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(54) **SYSTEM FOR TREATING EMBOLISM AND ASSOCIATED DEVICES AND METHODS**

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(56) **References Cited**

U.S. PATENT DOCUMENTS

1,101,890 A 6/1914 Tunstead
2,784,717 A 3/1957 Thompson
(Continued)

FOREIGN PATENT DOCUMENTS

AU 2015210338 8/2015
CN 102186427 9/2011
(Continued)

OTHER PUBLICATIONS

English translation of Japanese Office Action dated Jun. 7, 2023 for Japanese Application No. 2021-507564, 7 pages.
(Continued)

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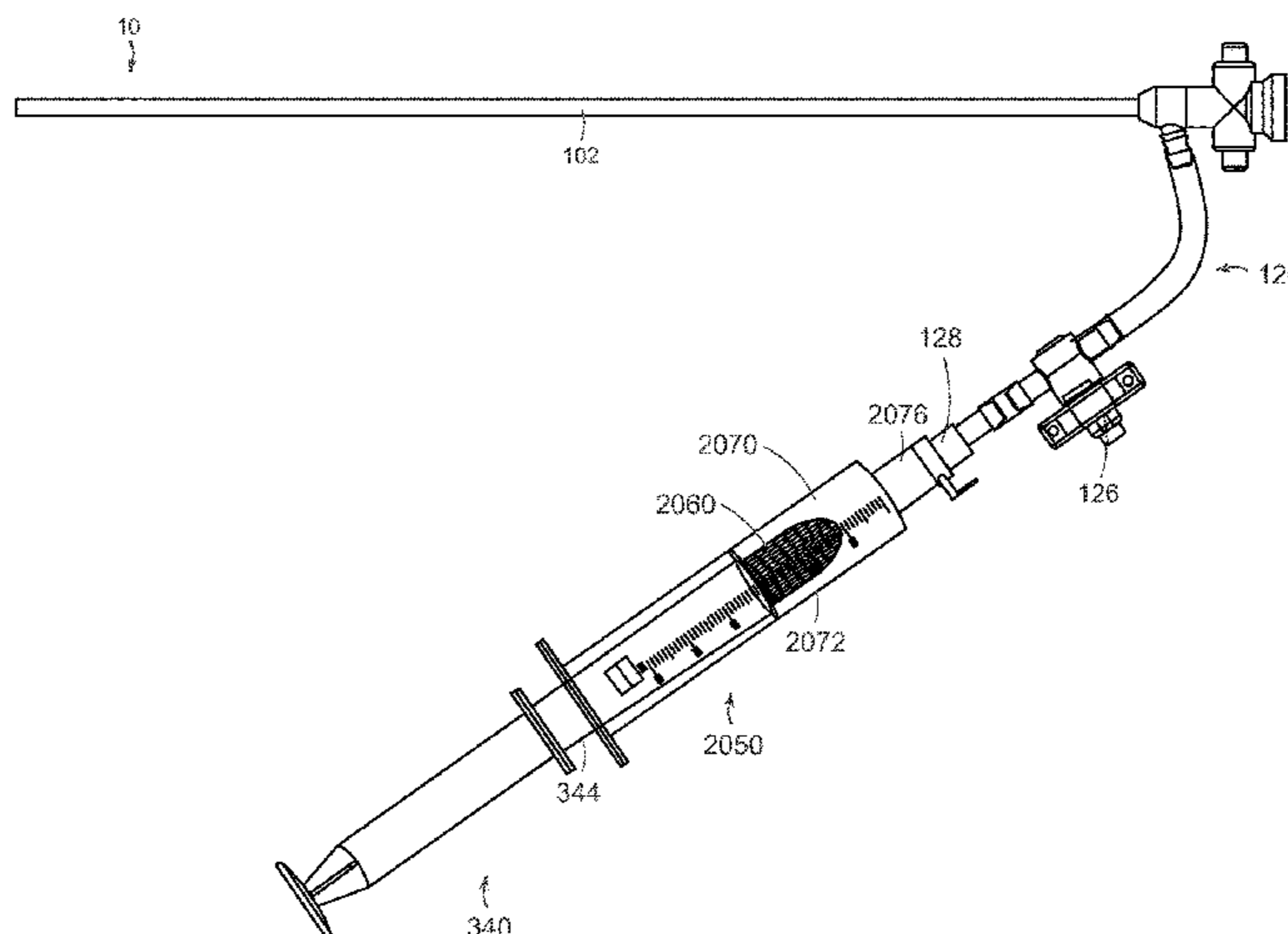
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(57) **ABSTRACT**

Systems and methods for the intravascular treatment of clot material within a blood vessel of a human patient are disclosed herein. A method in accordance with embodiments of the present technology can include, for example, positioning a distal portion of a catheter proximate to the clot material within the blood vessel. The method can further include coupling a pressure source to the catheter via a tubing subsystem including a valve or other fluid control device and, while the valve is closed, activating the pressure source to charge a vacuum. The valve can then be opened to apply the vacuum to the catheter to thereby aspirate at least a portion of the clot material from the blood vessel and into the catheter.

15 Claims, 38 Drawing Sheets



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(56) **References Cited**

U.S. PATENT DOCUMENTS

2,846,179 A 8/1958 Monckton
 2,955,592 A 10/1960 Maclean
 3,088,363 A 5/1963 Sparks
 3,197,173 A 7/1965 Taubenheim
 3,416,531 A 12/1968 Edwards
 3,435,826 A 4/1969 Fogarty
 3,438,607 A 4/1969 Williams et al.
 3,515,137 A 6/1970 Santomieri
 3,675,657 A 7/1972 Gauthier
 3,785,380 A 1/1974 Brumfield
 3,860,006 A 1/1975 Patel
 3,892,161 A 7/1975 Sokol
 3,923,065 A 12/1975 Nozick et al.
 4,030,503 A 6/1977 Clark, III
 4,034,642 A 7/1977 Iannucci et al.
 4,222,380 A 9/1980 Terayama
 4,243,040 A 1/1981 Beecher
 4,287,808 A 9/1981 Leonard et al.
 4,324,262 A 4/1982 Hall
 4,393,872 A 7/1983 Reznik et al.
 4,401,107 A 8/1983 Harber et al.
 4,469,100 A 9/1984 Hardwick
 4,523,738 A 6/1985 Raftis et al.
 4,551,862 A 11/1985 Haber
 4,604,094 A 8/1986 Shook
 4,611,594 A 9/1986 Grayhack et al.
 4,634,421 A 1/1987 Hegemann
 4,643,184 A 2/1987 Mobin-Uddin
 4,646,736 A 3/1987 Auth et al.
 4,650,466 A 3/1987 Luther
 4,776,337 A 10/1988 Palmaz
 4,790,812 A 12/1988 Hawkins, Jr. et al.
 4,863,440 A 9/1989 Chin et al.
 4,870,953 A 10/1989 DonMichael et al.
 4,883,458 A 11/1989 Shiber
 4,886,062 A 12/1989 Wiktor
 4,890,611 A 1/1990 Monfort et al.
 4,898,575 A 2/1990 Fischell et al.
 4,946,440 A 8/1990 Hall
 4,960,259 A 10/1990 Sunnavader et al.
 4,978,341 A 12/1990 Niederhauser
 4,981,478 A 1/1991 Evard et al.
 5,030,201 A 7/1991 Palestrant

5,059,178 A 10/1991 Ya
 5,100,423 A 3/1992 Fearnot
 5,127,626 A 7/1992 Hilal et al.
 5,129,910 A 7/1992 Phan et al.
 5,135,484 A 8/1992 Wright
 5,154,724 A 10/1992 Andrews
 5,158,533 A 10/1992 Strauss et al.
 5,158,564 A 10/1992 Schnepf-Pesch et al.
 5,192,274 A 3/1993 Bierman
 5,192,286 A 3/1993 Phan et al.
 5,192,290 A 3/1993 Hilal
 5,197,485 A 3/1993 Grooters
 5,234,403 A 8/1993 Yoda et al.
 5,242,461 A 9/1993 Kortenbach et al.
 5,244,619 A 9/1993 Burnham
 5,323,514 A 6/1994 Masuda et al.
 5,329,923 A 7/1994 Lundquist
 5,360,417 A 11/1994 Gravener et al.
 5,364,345 A 11/1994 Lowery et al.
 5,376,101 A 12/1994 Green et al.
 5,383,887 A 1/1995 Nadal
 5,389,100 A 2/1995 Bacich et al.
 5,391,152 A 2/1995 Patterson et al.
 5,419,774 A 5/1995 Willard et al.
 5,421,824 A 6/1995 Clement et al.
 5,443,443 A 8/1995 Shiber
 5,456,667 A 10/1995 Ham et al.
 5,476,450 A 12/1995 Ruggio
 5,484,418 A 1/1996 Quiachon et al.
 5,490,859 A 2/1996 Mische et al.
 5,496,365 A 3/1996 Sgro
 5,527,326 A 6/1996 Hermann et al.
 5,549,626 A 8/1996 Miller et al.
 5,591,137 A 1/1997 Stevens
 5,639,276 A 6/1997 Weinstock et al.
 5,653,684 A 8/1997 Laptewicz et al.
 5,662,703 A 9/1997 Yurek et al.
 5,746,758 A 5/1998 Nordgren et al.
 5,749,858 A 5/1998 Cramer
 5,769,816 A 6/1998 Barbut et al.
 5,782,817 A 7/1998 Franzel et al.
 5,800,457 A 9/1998 Gelbfish
 5,827,229 A 10/1998 Auth et al.
 5,846,251 A 12/1998 Hart
 5,860,938 A 1/1999 Lafontaine et al.
 5,873,866 A 2/1999 Kondo et al.
 5,873,882 A 2/1999 Straub et al.
 5,876,414 A 3/1999 Straub
 5,895,406 A 4/1999 Gray et al.
 5,908,435 A 6/1999 Samuels
 5,911,710 A 6/1999 Barry et al.
 5,911,728 A 6/1999 Sepetka et al.
 5,911,733 A 6/1999 Parodi
 5,911,754 A 6/1999 Kanesaka et al.
 5,941,869 A 8/1999 Patterson et al.
 5,947,985 A 9/1999 Imram
 5,951,539 A 9/1999 Nita et al.
 5,954,737 A 9/1999 Lee
 5,971,938 A 10/1999 Hart et al.
 5,971,958 A 10/1999 Zhang
 5,972,019 A 10/1999 Engelson et al.
 5,974,938 A 11/1999 Lloyd
 5,989,233 A 11/1999 Yoon
 5,993,483 A 11/1999 Gianotti
 6,017,335 A 1/2000 Burnham
 6,030,397 A 2/2000 Moneti et al.
 6,059,745 A 5/2000 Gelbfish
 6,059,814 A 5/2000 Ladd
 6,066,158 A 5/2000 Engelson et al.
 6,068,645 A 5/2000 Tu
 6,126,635 A 10/2000 Simpson et al.
 6,142,987 A 11/2000 Tsugita
 6,146,396 A 11/2000 Konya et al.
 6,146,403 A 11/2000 St. Germain
 6,152,144 A 11/2000 Lesh et al.
 6,152,946 A 11/2000 Broome et al.
 6,156,055 A 12/2000 Ravenscroft
 6,159,230 A 12/2000 Samuels
 6,165,196 A 12/2000 Stack et al.

(56)

References Cited

U.S. PATENT DOCUMENTS

6,168,579 B1	1/2001	Tsugita	6,960,222 B2	11/2005	Vo et al.
6,179,859 B1	1/2001	Bates et al.	7,004,931 B2	2/2006	Hogendijk
6,221,006 B1	4/2001	Dubrul et al.	7,004,954 B1	2/2006	Voss et al.
6,228,060 B1	5/2001	Howell	7,036,707 B2	5/2006	Aota et al.
6,238,412 B1	5/2001	Dubrul et al.	7,041,084 B2	5/2006	Fotjik
6,245,078 B1	6/2001	Ouchi	7,052,500 B2	5/2006	Bashiri et al.
6,245,089 B1	6/2001	Daniel et al.	7,056,328 B2	6/2006	Arnott
6,254,571 B1	7/2001	Hart	7,063,707 B2	6/2006	Bose et al.
6,258,115 B1	7/2001	Dubrul	7,069,835 B2	7/2006	Nishri et al.
6,264,663 B1	7/2001	Cano	7,094,249 B1	8/2006	Thomas et al.
6,306,163 B1	10/2001	Fitz	7,122,034 B2	10/2006	Belhe et al.
6,322,572 B1	11/2001	Lee	7,128,073 B1	10/2006	van der Burg et al.
6,350,271 B1	2/2002	Kurz et al.	7,152,605 B2	12/2006	Khairkhahan et al.
6,361,545 B1	3/2002	Macoviak et al.	7,179,273 B1	2/2007	Palmer et al.
6,364,895 B1	4/2002	Greenhalgh	7,223,253 B2	5/2007	Hogendijk
6,368,339 B1	4/2002	Amplatz	7,232,432 B2	6/2007	Fulton, III et al.
6,383,205 B1	5/2002	Samson et al.	7,244,243 B2	7/2007	Lary
6,402,771 B1	6/2002	Palmer et al.	7,285,126 B2	10/2007	Sepetka et al.
6,413,235 B1	7/2002	Parodi	7,300,458 B2	11/2007	Henkes et al.
6,423,032 B2	7/2002	Parodi	7,306,618 B2	12/2007	Demond et al.
6,432,122 B1	8/2002	Gilson et al.	7,320,698 B2	1/2008	Eskuri
6,451,036 B1	9/2002	Heitzmann et al.	7,323,002 B2	1/2008	Johnson et al.
6,458,103 B1	10/2002	Albert et al.	7,331,980 B2	2/2008	Dubrul et al.
6,475,236 B1	11/2002	Roubin et al.	7,481,805 B2	1/2009	Magnusson
6,485,502 B2	11/2002	Don Michael	7,534,234 B2	5/2009	Fotjik
6,508,782 B1	1/2003	Evans et al.	7,578,830 B2	8/2009	Kusleika et al.
6,511,492 B1	1/2003	Rosenbluth et al.	7,621,870 B2	11/2009	Berrada et al.
6,514,273 B1	2/2003	Voss et al.	7,674,247 B2	3/2010	Fotjik
6,530,923 B1	3/2003	Dubrul et al.	7,678,131 B2	3/2010	Muller
6,530,935 B2	3/2003	Wensel et al.	7,691,121 B2	4/2010	Rosenbluth et al.
6,540,722 B1	4/2003	Boyle et al.	7,695,458 B2	4/2010	Belley et al.
6,544,276 B1	4/2003	Azizi	7,713,282 B2	5/2010	Frazier et al.
6,544,278 B1	4/2003	Vrba et al.	7,722,641 B2	5/2010	van der Burg et al.
6,544,279 B1	4/2003	Hopkins et al.	7,763,010 B2	7/2010	Evans et al.
6,551,342 B1	4/2003	Shen et al.	7,766,934 B2	8/2010	Pal et al.
6,564,828 B1	5/2003	Ishida	7,775,501 B2	8/2010	Kees
6,569,181 B1	5/2003	Burns	7,780,696 B2	8/2010	Daniel et al.
6,575,995 B1	6/2003	Huter et al.	7,815,608 B2	10/2010	Schafersman et al.
6,589,263 B1	7/2003	Hopkins et al.	7,837,630 B2	11/2010	Nieoson et al.
6,589,264 B1	7/2003	Barbut et al.	7,905,877 B1	3/2011	Jilnenez et al.
6,596,011 B2	7/2003	Johnson et al.	7,905,896 B2	3/2011	Straub
6,602,271 B2	8/2003	Adams et al.	7,938,809 B2	5/2011	Lampropoulos et al.
6,605,074 B2	8/2003	Zadno-azizi et al.	7,938,820 B2	5/2011	Webster et al.
6,605,102 B1	8/2003	Mazzocchi et al.	7,967,790 B2	6/2011	Whiting et al.
6,610,077 B1	8/2003	Hancock et al.	7,976,511 B2	7/2011	Fotjik
6,620,148 B1	9/2003	Tsugita	7,993,302 B2	8/2011	Hebert et al.
6,620,179 B2	9/2003	Brook et al.	7,993,363 B2	8/2011	Demond et al.
6,620,182 B1	9/2003	Khosravi et al.	8,021,351 B2	9/2011	Boldenow et al.
6,623,460 B1	9/2003	Heck	8,043,313 B2	10/2011	Krolik et al.
6,635,068 B1	10/2003	Dubrul et al.	8,052,640 B2	11/2011	Fiorella et al.
6,645,222 B1	11/2003	Parodi et al.	8,057,496 B2	11/2011	Fischer, Jr.
6,660,013 B2	12/2003	Rabiner et al.	8,057,497 B1	11/2011	Raju et al.
6,660,014 B2	12/2003	Demarais et al.	8,066,757 B2	11/2011	Ferrera et al.
6,663,650 B2	12/2003	Sepetka et al.	8,070,694 B2	12/2011	Galdonik et al.
6,692,504 B2	2/2004	Kurz et al.	8,070,769 B2	12/2011	Broome
6,699,260 B2	3/2004	Dubrul et al.	8,070,791 B2	12/2011	Ferrera et al.
6,702,830 B1	3/2004	Demarais et al.	8,075,510 B2	12/2011	Aklog et al.
6,719,717 B1	4/2004	Johnson et al.	8,080,032 B2	12/2011	van der Burg et al.
6,755,847 B2	6/2004	Eskuri	8,088,140 B2	1/2012	Ferrera et al.
6,767,353 B1 *	7/2004	Shiber A61B 17/22 606/159	8,092,486 B2	1/2012	Berrada et al.
6,790,204 B2	9/2004	Zadno-azizi et al.	8,100,935 B2	1/2012	Rosenbluth et al.
6,800,080 B1	10/2004	Bates	8,109,962 B2	2/2012	Pal
6,818,006 B2	11/2004	Douk et al.	8,118,829 B2	2/2012	Carrison et al.
6,824,545 B2	11/2004	Sepetka et al.	8,197,493 B2	6/2012	Ferrera et al.
6,824,550 B1	11/2004	Noriega et al.	8,246,641 B2	8/2012	Osborne et al.
6,824,553 B1	11/2004	Gene et al.	8,261,648 B1	9/2012	Marchand et al.
6,830,561 B2	12/2004	Jansen et al.	8,267,897 B2	9/2012	Wells
6,846,029 B1	1/2005	Ragner et al.	8,298,257 B2	10/2012	Sepetka et al.
6,902,540 B2	6/2005	Dorros et al.	8,317,748 B2	11/2012	Fiorella et al.
6,908,455 B2	6/2005	Hajianpour	8,337,450 B2	12/2012	Fotjik
6,939,361 B1	9/2005	Kleshinski	RE43,902 E	1/2013	Hopkins et al.
6,942,682 B2	9/2005	Vrba et al.	8,343,167 B2	1/2013	Henson
6,945,977 B2	9/2005	Demarais et al.	8,357,178 B2	1/2013	Grandfield et al.
6,960,189 B2	11/2005	Bates et al.	8,361,104 B2	1/2013	Jones et al.
			8,409,215 B2	4/2013	Sepetka et al.
			8,480,708 B2	7/2013	Kassab et al.
			8,486,105 B2	7/2013	Demond et al.
			8,491,539 B2	7/2013	Fotjik
			8,512,352 B2	8/2013	Martin

(56)

References Cited

U.S. PATENT DOCUMENTS

8,523,897 B2	9/2013	van der Burg et al.		9,581,942 B1	2/2017	Shippert
8,535,283 B2 *	9/2013	Heaton	A61M 1/98 604/319	9,616,213 B2	4/2017	Furnish et al.
8,535,334 B2	9/2013	Martin		9,636,206 B2	5/2017	Nguyen et al.
8,535,343 B2	9/2013	van der Burg et al.		9,643,035 B2	5/2017	Mastenbroek
8,545,526 B2	10/2013	Martin et al.		9,662,129 B2	5/2017	Galdonik et al.
8,568,432 B2	10/2013	Straub		9,700,332 B2	7/2017	Marchand et al.
8,568,465 B2	10/2013	Freudenthal et al.		9,717,488 B2	8/2017	Kassab et al.
8,574,262 B2	11/2013	Ferrera et al.		9,717,514 B2	8/2017	Martin et al.
8,579,915 B2	11/2013	French et al.		9,717,519 B2	8/2017	Rosenbluth et al.
8,585,713 B2	11/2013	Ferrera et al.		9,744,024 B2	8/2017	Nguyen et al.
8,608,754 B2	12/2013	Wensel et al.		9,757,137 B2	9/2017	Krolik et al.
8,647,367 B2	2/2014	Kassab et al.		9,827,084 B2	11/2017	Bonnette et al.
8,657,867 B2	2/2014	Dorn et al.		9,844,386 B2	12/2017	Nguyen et al.
8,696,622 B2	4/2014	Fiorella et al.		9,844,387 B2	12/2017	Marchand et al.
8,715,314 B1	5/2014	Janardhan et al.		9,848,975 B2	12/2017	Hauser
8,721,714 B2	5/2014	Kelley		9,849,014 B2	12/2017	Kusleika
8,753,322 B2 *	6/2014	Hu	A61M 1/81 604/319	9,884,387 B2	2/2018	Plha
8,771,289 B2	7/2014	Mohiuddin et al.		9,962,178 B2	5/2018	Greenhalgh et al.
8,777,893 B2	7/2014	Malewicz		9,980,813 B2	5/2018	Eller
8,784,441 B2	7/2014	Rosenbluth et al.		9,999,493 B2	6/2018	Nguyen et al.
8,784,442 B2	7/2014	Jones et al.		10,004,531 B2	6/2018	Rosenbluth et al.
8,784,469 B2	7/2014	Kassab		10,010,335 B2	7/2018	Greenhalgh et al.
8,795,305 B2	8/2014	Martin et al.		10,016,266 B2	7/2018	Hauser
8,795,345 B2	8/2014	Grandfield et al.		10,028,759 B2	7/2018	Wallace et al.
8,801,748 B2	8/2014	Martin		10,045,790 B2	8/2018	Cox et al.
8,808,259 B2	8/2014	Walton et al.		10,058,339 B2	8/2018	Galdonik et al.
8,814,927 B2	8/2014	Shin et al.		10,098,651 B2	10/2018	Marchand et al.
8,820,207 B2	9/2014	Marchand et al.		10,130,385 B2	11/2018	Farhangnia et al.
8,826,791 B2	9/2014	Thompson et al.		10,183,159 B2	1/2019	Nobles et al.
8,828,044 B2	9/2014	Aggerholm et al.		10,226,263 B2	3/2019	Look et al.
8,833,224 B2	9/2014	Thompson et al.		10,238,406 B2	3/2019	Cox et al.
8,834,519 B2	9/2014	van der Burg et al.		10,271,864 B2	4/2019	Greenhalgh et al.
8,845,621 B2	9/2014	Fotjik		10,327,883 B2	6/2019	Yachia
8,852,205 B2	10/2014	Brady et al.		10,335,186 B2	7/2019	Rosenbluth et al.
8,852,226 B2	10/2014	Gilson et al.		10,342,571 B2	7/2019	Marchand et al.
8,939,991 B2	1/2015	Krolik et al.		10,349,960 B2	7/2019	Quick
8,945,143 B2	2/2015	Ferrera et al.		10,383,644 B2	8/2019	Molaei et al.
8,945,172 B2	2/2015	Ferrera et al.		10,384,034 B2	8/2019	Carrison et al.
8,956,384 B2	2/2015	Berrada et al.		10,456,555 B2	10/2019	Carrison et al.
8,992,504 B2	3/2015	Castella et al.		10,478,535 B2 *	11/2019	Ogle A61M 25/0662
9,005,172 B2	4/2015	Chung		10,485,952 B2	11/2019	Carrison et al.
9,011,551 B2	4/2015	Oral et al.		10,524,811 B2	1/2020	Marchand et al.
9,028,401 B1	5/2015	Bacich et al.		10,531,883 B1 *	1/2020	Deville A61F 2/013
9,078,682 B2	7/2015	Lenker et al.		10,588,655 B2	3/2020	Rosenbluth et al.
9,101,382 B2	8/2015	Krolik et al.		10,648,268 B2	5/2020	Jaffrey et al.
9,125,683 B2	9/2015	Farhangnia et al.		10,695,159 B2	6/2020	Hauser
9,126,016 B2	9/2015	Fulton		10,709,471 B2	7/2020	Rosenbluth et al.
9,149,609 B2	10/2015	Ansel et al.		10,772,636 B2	9/2020	Kassab et al.
9,155,552 B2	10/2015	Ulm, III		10,799,331 B2	10/2020	Hauser
9,161,766 B2	10/2015	Slee et al.		10,912,577 B2	2/2021	Marchand et al.
9,168,043 B2	10/2015	van der Burg et al.		10,926,060 B2	2/2021	Stern et al.
9,173,668 B2	11/2015	Ulm, III		10,953,195 B2	3/2021	Jalgaonkar et al.
9,186,487 B2	11/2015	Dubrul et al.		10,960,114 B2	3/2021	Goisis
9,204,887 B2	12/2015	Cully et al.		11,000,682 B2	5/2021	Merritt et al.
9,216,277 B2	12/2015	Myers		11,013,523 B2	5/2021	Arad Hadar
9,241,669 B2	1/2016	Pugh et al.		11,058,445 B2	7/2021	Cox et al.
9,358,037 B2	1/2016	Farhangnia et al.		11,058,451 B2	7/2021	Marchand et al.
9,259,237 B2	2/2016	Quick et al.		11,065,019 B1	7/2021	Chou et al.
9,265,512 B2	2/2016	Carrison et al.		11,147,571 B2	10/2021	Cox et al.
9,283,066 B2	3/2016	Hopkins et al.		11,154,314 B2	10/2021	Quick
9,301,769 B2	4/2016	Brady et al.		11,166,703 B2	11/2021	Kassab et al.
9,351,747 B2	5/2016	Kugler et al.		11,185,664 B2	11/2021	Carrison et al.
9,439,664 B2	9/2016	Sos		11,213,356 B2	1/2022	Tanner et al.
9,439,751 B2	9/2016	White et al.		11,224,450 B2	1/2022	Chou et al.
9,456,834 B2	10/2016	Folk		11,224,721 B2	1/2022	Carrison et al.
9,463,035 B1	10/2016	Greenhalgh et al.		11,259,821 B2	3/2022	Buck et al.
9,463,036 B2	10/2016	Brady et al.		11,305,094 B2	4/2022	Carrison et al.
9,526,864 B2	12/2016	Quick		11,383,064 B2	7/2022	Carrison et al.
9,526,865 B2	12/2016	Quick		11,395,903 B2	7/2022	Carrison et al.
9,532,792 B2	1/2017	Galdonik et al.		11,406,801 B2	8/2022	Fojtik et al.
9,566,073 B2	2/2017	Kassab et al.		11,433,218 B2	9/2022	Quick et al.
9,566,424 B2	2/2017	Pessin		11,439,799 B2	9/2022	Buck et al.
9,579,116 B1	2/2017	Nguyen et al.		11,457,936 B2	10/2022	Buck et al.
				11,529,158 B2	12/2022	Hauser
				11,554,005 B2	1/2023	Merritt et al.
				11,559,382 B2	1/2023	Merritt et al.
				11,576,691 B2	2/2023	Chou et al.
				11,596,768 B2	3/2023	Stern et al.
				11,642,209 B2	5/2023	Merritt et al.

(56)

References Cited

U.S. PATENT DOCUMENTS

11,648,028 B2	5/2023	Rosenbluth et al.	2004/0260344 A1	12/2004	Lyons et al.
11,697,011 B2	7/2023	Merritt et al.	2004/0267272 A1	12/2004	Henniges et al.
11,697,012 B2	7/2023	Merritt et al.	2005/0004534 A1	1/2005	Lockwood et al.
11,744,691 B2	9/2023	Merritt et al.	2005/0033172 A1	2/2005	Dubrul et al.
11,806,033 B2	11/2023	Marchand et al.	2005/0038468 A1	2/2005	Panetta et al.
11,832,837 B2	12/2023	Hauser	2005/0054995 A1	3/2005	Barzell et al.
11,832,838 B2	12/2023	Hauser	2005/0055047 A1	3/2005	Greenhalgh
11,833,023 B2	12/2023	Merritt et al.	2005/0085769 A1	4/2005	MacMahon et al.
11,839,393 B2	12/2023	Hauser	2005/0085826 A1	4/2005	Nair et al.
11,844,921 B2	12/2023	Merritt et al.	2005/0085846 A1	4/2005	Carrison et al.
11,849,963 B2	12/2023	Quick	2005/0085849 A1	4/2005	Sepetka et al.
11,865,291 B2	1/2024	Merritt et al.	2005/0119668 A1	6/2005	Teague et al.
11,890,180 B2	2/2024	Merritt et al.	2005/0131387 A1	6/2005	Pursley
11,918,243 B2	3/2024	Marchand et al.	2005/0177132 A1	8/2005	Lentz et al.
11,918,244 B2	3/2024	Marchand et al.	2005/0187570 A1	8/2005	Nguyen et al.
11,925,369 B2	3/2024	Hauser	2005/0203605 A1	9/2005	Dolan
11,937,834 B2	3/2024	Dinh	2005/0283165 A1	12/2005	Gadberry
11,937,838 B2	3/2024	Cox et al.	2005/0283166 A1	12/2005	Greenhalgh et al.
2001/0004699 A1	6/2001	Gittings et al.	2005/0283186 A1	12/2005	Berrada et al.
2001/0031981 A1	10/2001	Evans et al.	2006/0020286 A1	1/2006	Niermann
2001/0041881 A1	11/2001	Sarge et al.	2006/0042786 A1	3/2006	West
2001/0041909 A1	11/2001	Tsugita et al.	2006/0047286 A1	3/2006	West
2001/0049486 A1	12/2001	Evans et al.	2006/0074401 A1	4/2006	Ross
2001/0051810 A1	12/2001	Dubrul et al.	2006/0089533 A1	4/2006	Ziegler et al.
2002/0022858 A1	2/2002	Demond et al.	2006/0100662 A1	5/2006	Daniel et al.
2002/0022859 A1	2/2002	Hogendijk	2006/0155305 A1	7/2006	Freudenthal et al.
2002/0026211 A1	2/2002	Khosravi et al.	2006/0173525 A1	8/2006	Behl et al.
2002/0032455 A1	3/2002	Boock et al.	2006/0195137 A1	8/2006	Sepetka et al.
2002/0049452 A1	4/2002	Kurz et al.	2006/0200221 A1	9/2006	Malewicz
2002/0095161 A1	7/2002	Dhindsa	2006/0217664 A1	9/2006	Hattler et al.
2002/0095171 A1	7/2002	Belef	2006/0224177 A1	10/2006	Finitsis
2002/0111648 A1	8/2002	Kusleika et al.	2006/0229645 A1	10/2006	Bonnette et al.
2002/0120277 A1	8/2002	Hauschild et al.	2006/0247500 A1	11/2006	Voegele et al.
2002/0147458 A1	10/2002	Hiblar et al.	2006/0253145 A1	11/2006	Lucas
2002/0151918 A1	10/2002	Lafontaine et al.	2006/0264905 A1	11/2006	Esckridge et al.
2002/0156457 A1	10/2002	Fisher	2006/0276874 A1	12/2006	Wilson et al.
2002/0161392 A1	10/2002	Dubrul	2006/0282111 A1	12/2006	Morsi
2002/0169474 A1	11/2002	Kusleika	2006/0293696 A1	12/2006	Fahey et al.
2002/0173819 A1	11/2002	Leefflang et al.	2007/0010787 A1	1/2007	Hackett et al.
2002/0188276 A1	12/2002	Evans et al.	2007/0038225 A1	2/2007	Osborne
2003/0023263 A1	1/2003	Krolik et al.	2007/0093744 A1	4/2007	Elmaleh
2003/0083693 A1	5/2003	Daniel et al.	2007/0112374 A1	5/2007	Paul et al.
2003/0100919 A1	5/2003	Hopkins et al.	2007/0118165 A1	5/2007	DeMello et al.
2003/0114875 A1	6/2003	Sjostrom	2007/0149996 A1	6/2007	Coughlin
2003/0116731 A1*	6/2003	Hartley F16K 7/06 251/297	2007/0161963 A1	7/2007	Smalling
2003/0125663 A1	7/2003	Coleman et al.	2007/0179513 A1	8/2007	Deutsch
2003/0135151 A1	7/2003	Deng	2007/0191866 A1	8/2007	Palmer et al.
2003/0135230 A1	7/2003	Massey et al.	2007/0198028 A1	8/2007	Miloslavski et al.
2003/0135258 A1	7/2003	Andreas et al.	2007/0208361 A1	9/2007	Okushi et al.
2003/0153873 A1	8/2003	Luther et al.	2007/0208367 A1	9/2007	Fiorella et al.
2003/0153973 A1	8/2003	Soun et al.	2007/0213753 A1	9/2007	Waller
2003/0168068 A1	9/2003	Poole et al.	2007/0213765 A1	9/2007	Adams et al.
2003/0176884 A1	9/2003	Berrada et al.	2007/0233043 A1	10/2007	Dayton et al.
2003/0191516 A1	10/2003	Weldon et al.	2007/0255252 A1	11/2007	Mehta
2003/0208224 A1	11/2003	Broome	2007/0288054 A1	12/2007	Tanaka et al.
2003/0216774 A1	11/2003	Larson	2008/0015541 A1	1/2008	Rosenbluth et al.
2003/0225379 A1	12/2003	Schaffer et al.	2008/0087853 A1	4/2008	Kees
2004/0019310 A1*	1/2004	Hogendijk A61M 1/3621 604/1	2008/0088055 A1	4/2008	Ross
2004/0039351 A1	2/2004	Barrett	2008/0157017 A1	7/2008	Macatangay et al.
2004/0039412 A1	2/2004	Isshiki et al.	2008/0167678 A1	7/2008	Morsi
2004/0068288 A1	4/2004	Palmer et al.	2008/0183136 A1	7/2008	Lenker et al.
2004/0073243 A1	4/2004	Sepetka et al.	2008/0228209 A1	9/2008	DeMello et al.
2004/0098033 A1	5/2004	Leefflang et al.	2008/0234715 A1	9/2008	Pesce et al.
2004/0102807 A1	5/2004	Kusleika et al.	2008/0234722 A1	9/2008	Bonnette et al.
2004/0122359 A1*	6/2004	Wenz B01F 35/713 604/82	2008/0262528 A1	10/2008	Martin
2004/0127936 A1	7/2004	Salahieh et al.	2008/0269798 A1	10/2008	Ramzipoor et al.
2004/0133232 A1	7/2004	Rosenbluth et al.	2008/0294096 A1	11/2008	Uber, III et al.
2004/0138525 A1	7/2004	Saadat et al.	2008/0300466 A1	12/2008	Gresham
2004/0138692 A1	7/2004	Phung et al.	2008/0312681 A1	12/2008	Ansel et al.
2004/0167567 A1	8/2004	Cano et al.	2009/0018566 A1	1/2009	Escudero et al.
2004/0199201 A1	10/2004	Kellett et al.	2009/0054918 A1	2/2009	Henson
2004/0199202 A1	10/2004	Dubrul et al.	2009/0062841 A1	3/2009	Amplatz et al.
			2009/0069828 A1	3/2009	Martin et al.
			2009/0076417 A1	3/2009	Jones
			2009/0160112 A1	6/2009	Ostrovsky
			2009/0163846 A1	6/2009	Aklog et al.
			2009/0182362 A1	7/2009	Thompson et al.
			2009/0192495 A1	7/2009	Ostrovsky et al.
			2009/0281525 A1	11/2009	Harding et al.

(56)

References Cited

U.S. PATENT DOCUMENTS

2009/0292307	A1	11/2009	Razack	2013/0102996	A1	4/2013	Strauss
2009/0299393	A1	12/2009	Martin et al.	2013/0116708	A1	5/2013	Ziniti et al.
2009/0312786	A1	12/2009	Trask et al.	2013/0116721	A1	5/2013	Takagi et al.
2010/0016837	A1	1/2010	Howat	2013/0123705	A1	5/2013	Holm et al.
2010/0030256	A1	2/2010	Dubrul et al.	2013/0126559	A1	5/2013	Cowan et al.
2010/0042136	A1	2/2010	Berrada et al.	2013/0144326	A1	6/2013	Brady et al.
2010/0087844	A1	4/2010	Fischer, Jr.	2013/0150793	A1	6/2013	Beissel et al.
2010/0087850	A1	4/2010	Razack	2013/0165871	A1	6/2013	Fiorella et al.
2010/0094201	A1	4/2010	Mallaby	2013/0184703	A1	7/2013	Shireman et al.
2010/0106081	A1	4/2010	Brandeis	2013/0190701	A1	7/2013	Kirn
2010/0114017	A1	5/2010	Lenker et al.	2013/0197454	A1	8/2013	Shibata et al.
2010/0114113	A1	5/2010	Dubrul et al.	2013/0197567	A1	8/2013	Brady et al.
2010/0121312	A1	5/2010	Gielenz et al.	2013/0204297	A1	8/2013	Melsheimer et al.
2010/0137846	A1	6/2010	Desai et al.	2013/0226196	A1	8/2013	Smith
2010/0190156	A1	7/2010	Van Wordragen et al.	2013/0270161	A1	10/2013	Kumar et al.
2010/0204712	A1	8/2010	Mallaby	2013/0281788	A1	10/2013	Garrison
2010/0217276	A1	8/2010	Garrison et al.	2013/0289608	A1	10/2013	Tanaka et al.
2010/0249815	A1	9/2010	Jantzen et al.	2013/0317589	A1	11/2013	Martin et al.
2010/0268264	A1	10/2010	Bonnette et al.	2013/0345739	A1	12/2013	Brady et al.
2010/0318178	A1	12/2010	Rapaport et al.	2014/0005712	A1	1/2014	Martin
2011/0034986	A1	2/2011	Chou et al.	2014/0005713	A1	1/2014	Bowman
2011/0034987	A1	2/2011	Kennedy	2014/0005715	A1	1/2014	Castella et al.
2011/0054405	A1	3/2011	Whiting et al.	2014/0005717	A1	1/2014	Martin et al.
2011/0060212	A1	3/2011	Slee et al.	2014/0025048	A1	1/2014	Ward
2011/0071503	A1	3/2011	Takagi et al.	2014/0031856	A1	1/2014	Martin
2011/0118817	A1	5/2011	Gunderson et al.	2014/0046133	A1	2/2014	Nakamura et al.
2011/0125181	A1	5/2011	Brady et al.	2014/0046243	A1	2/2014	Ray et al.
2011/0144592	A1	6/2011	Wong et al.	2014/0052161	A1	2/2014	Cully et al.
2011/0152823	A1	6/2011	Mohiuddin et al.	2014/0074144	A1	3/2014	Shrivastava et al.
2011/0152889	A1	6/2011	Ashland	2014/0121672	A1	5/2014	Folk
2011/0152993	A1	6/2011	Marchand et al.	2014/0155830	A1*	6/2014	Bonnette A61M 25/0026 604/150
2011/0160742	A1	6/2011	Ferrera et al.	2014/0155980	A1	6/2014	Turjman
2011/0160763	A1	6/2011	Ferrera et al.	2014/0163615	A1	6/2014	Gadlage et al.
2011/0190806	A1	8/2011	Wittens	2014/0180055	A1	6/2014	Glynn et al.
2011/0196309	A1*	8/2011	Wells A61M 5/14216 604/173	2014/0180397	A1	6/2014	Gerberding et al.
2011/0196414	A1	8/2011	Porter et al.	2014/0155908	A1	7/2014	Rosenbluth et al.
2011/0213290	A1	9/2011	Chin et al.	2014/0188127	A1	7/2014	Dubrul et al.
2011/0213403	A1	9/2011	Aboytes	2014/0188143	A1	7/2014	Martin et al.
2011/0224707	A1	9/2011	Miloslavski et al.	2014/0222070	A1	8/2014	Belson et al.
2011/0245807	A1	10/2011	Sakata et al.	2014/0236219	A1	8/2014	Dubrul et al.
2011/0251629	A1	10/2011	Galdonik et al.	2014/0243882	A1	8/2014	Ma
2011/0264132	A1	10/2011	Strauss et al.	2014/0257253	A1	9/2014	Jemison
2011/0264133	A1	10/2011	Hanlon et al.	2014/0257363	A1*	9/2014	Lippert A61B 17/12031 606/200
2011/0265681	A1	11/2011	Allen et al.	2014/0276403	A1	9/2014	Follmer et al.
2011/0288529	A1	11/2011	Fulton	2014/0296868	A1	10/2014	Garrison et al.
2011/0288572	A1	11/2011	Martin	2014/0303658	A1	10/2014	Bonnette et al.
2011/0309037	A1	12/2011	Lee	2014/0318354	A1	10/2014	Thompson et al.
2011/0319917	A1	12/2011	Ferrera et al.	2014/0324091	A1	10/2014	Rosenbluth et al.
2012/0059309	A1	3/2012	di Palma et al.	2014/0330286	A1	11/2014	Wallace et al.
2012/0059356	A1	3/2012	di Palma et al.	2014/0336691	A1	11/2014	Jones et al.
2012/0083824	A1	4/2012	Berrada et al.	2014/0343593	A1	11/2014	Chin et al.
2012/0083868	A1	4/2012	Shrivastava	2014/0364896	A1	12/2014	Consigny
2012/0089216	A1	4/2012	Rapaport et al.	2014/0371779	A1	12/2014	Vale et al.
2012/0095448	A1	4/2012	Kajii	2015/0005781	A1	1/2015	Lund-Clausen et al.
2012/0101480	A1	4/2012	Ingle et al.	2015/0005792	A1	1/2015	Ahn
2012/0101510	A1	4/2012	Lenker et al.	2015/0018859	A1	1/2015	Quick et al.
2012/0109109	A1	5/2012	Kajii	2015/0018860	A1	1/2015	Quick
2012/0138832	A1	6/2012	Townsend	2015/0018929	A1	1/2015	Martin et al.
2012/0143239	A1	6/2012	Aklog et al.	2015/0025555	A1	1/2015	Sos
2012/0165919	A1	6/2012	Cox et al.	2015/0032144	A1	1/2015	Holloway
2012/0172918	A1	7/2012	Fifer et al.	2015/0059908	A1	3/2015	Mollen
2012/0179181	A1	7/2012	Straub et al.	2015/0088190	A1	3/2015	Jensen
2012/0197277	A1	8/2012	Stinis	2015/0127035	A1	5/2015	Trapp et al.
2012/0232655	A1	9/2012	Lorrison et al.	2015/0133990	A1	5/2015	Davidson
2012/0271105	A1	10/2012	Nakamura et al.	2015/0150672	A1	6/2015	Ma
2012/0271231	A1	10/2012	Agrawal	2015/0164523	A1	6/2015	Brady et al.
2012/0277788	A1	11/2012	Cattaneo	2015/0164666	A1	6/2015	Johnson et al.
2012/0310166	A1	12/2012	Huff	2015/0173782	A1	6/2015	Garrison et al.
2013/0030460	A1	1/2013	Marks et al.	2015/0190155	A1	7/2015	Ulm, III
2013/0035628	A1	2/2013	Garrison et al.	2015/0190156	A1	7/2015	Ulm, III
2013/0046332	A1	2/2013	Jones et al.	2015/0196380	A1	7/2015	Berrada et al.
2013/0066348	A1	3/2013	Fiorella et al.	2015/0196744	A1	7/2015	Aboytes
2013/0092012	A1	4/2013	Marchand et al.	2015/0209058	A1	7/2015	Ferrera et al.
2013/0096571	A1	4/2013	Massicotte et al.	2015/0209165	A1	7/2015	Grandfield et al.
				2015/0238207	A1	8/2015	Cox et al.
				2015/0250578	A1	9/2015	Cook et al.
				2015/0265299	A1	9/2015	Cooper et al.

(56)

References Cited

U.S. PATENT DOCUMENTS

2015/0305756	A1	10/2015	Rosenbluth	2018/0125512	A1	5/2018	Nguyen et al.
2015/0305859	A1	10/2015	Eller	2018/0184912	A1*	7/2018	Al-Ali A61M 39/24
2015/0352325	A1	12/2015	Quick	2018/0193043	A1	7/2018	Marchand et al.
2015/0360001	A1	12/2015	Quick	2018/0236205	A1	8/2018	Krautkremer et al.
2015/0374391	A1	12/2015	Quick	2018/0250498	A1	9/2018	Stern et al.
2016/0022293	A1	1/2016	Dubrul et al.	2018/0256177	A1	9/2018	Cooper et al.
2016/0030708	A1	2/2016	Casiello et al.	2018/0256178	A1	9/2018	Cox et al.
2016/0038267	A1	2/2016	Allen et al.	2018/0296240	A1	10/2018	Rosenbluth et al.
2016/0058540	A1	3/2016	Don Michael	2018/0344339	A1	12/2018	Cox et al.
2016/0074627	A1	3/2016	Cottone	2018/0361116	A1	12/2018	Quick et al.
2016/0106353	A1*	4/2016	Schuetz A61M 1/34 210/416.1	2019/0000492	A1	1/2019	Casey et al.
2016/0106448	A1	4/2016	Brady et al.	2019/0015298	A1*	1/2019	Beatty A61J 1/2096
2016/0106449	A1	4/2016	Brady et al.	2019/0046219	A1	2/2019	Marchand et al.
2016/0113663	A1	4/2016	Brady et al.	2019/0070401	A1	3/2019	Merritt et al.
2016/0113664	A1	4/2016	Brady et al.	2019/0117244	A1	4/2019	Wallace et al.
2016/0113665	A1	4/2016	Brady et al.	2019/0133622	A1	5/2019	Wallace et al.
2016/0113666	A1	4/2016	Quick	2019/0133623	A1	5/2019	Wallace et al.
2016/0135829	A1	5/2016	Holochwost et al.	2019/0133624	A1	5/2019	Wallace et al.
2016/0143721	A1	5/2016	Rosenbluth	2019/0133625	A1	5/2019	Wallace et al.
2016/0151605	A1	6/2016	Welch et al.	2019/0133626	A1	5/2019	Wallace et al.
2016/0192912	A1	7/2016	Kassab et al.	2019/0133627	A1	5/2019	Wallace et al.
2016/0206344	A1	7/2016	Bruzzi et al.	2019/0150959	A1	5/2019	Cox et al.
2016/0008014	A1	8/2016	Rosenbluth	2019/0223893	A1	7/2019	Gilvarry et al.
2016/0220741	A1	8/2016	Garrison et al.	2019/0231373	A1	8/2019	Quick
2016/0220795	A1	8/2016	Korkuch et al.	2019/0239910	A1	8/2019	Brady et al.
2016/0228134	A1	8/2016	Martin et al.	2019/0321071	A1	10/2019	Marchand et al.
2016/0262774	A1	9/2016	Honda	2019/0328411	A1	10/2019	Vale et al.
2016/0262790	A1	9/2016	Rosenbluth et al.	2019/0336142	A1	11/2019	Torrie et al.
2016/0287276	A1	10/2016	Cox et al.	2019/0336148	A1	11/2019	Greenhalgh et al.
2016/0367285	A1	12/2016	Sos	2019/0365395	A1	12/2019	Tran et al.
2017/0014560	A1	1/2017	Minskoff et al.	2019/0366036	A1	12/2019	Jalgaonkar et al.
2017/0021130	A1	1/2017	Dye	2020/0022711	A1	1/2020	Look et al.
2017/0037548	A1	2/2017	Lee	2020/0046368	A1	2/2020	Merritt et al.
2017/0042571	A1	2/2017	Levi	2020/0046940	A1	2/2020	Carrison et al.
2017/0049942	A1	2/2017	Conlan et al.	2020/0054861	A1	2/2020	Korkuch et al.
2017/0056032	A1*	3/2017	Look A61M 1/74	2020/0113412	A1	4/2020	Jensen
2017/0058623	A1	3/2017	Jaffrey et al.	2020/0121334	A1	4/2020	Galdonik et al.
2017/0079672	A1	3/2017	Quick	2020/0129741	A1	4/2020	Kawwas et al.
2017/0086864	A1	3/2017	Greenhalgh et al.	2021/0022843	A1	1/2021	Hauser
2017/0100142	A1	4/2017	Look et al.	2021/0038385	A1	2/2021	Popp et al.
2017/0105743	A1	4/2017	Vale et al.	2021/0113224	A1	4/2021	Dinh
2017/0105745	A1	4/2017	Rosenbluth et al.	2021/0128182	A1	5/2021	Teigen et al.
2017/0112514	A1	4/2017	Marchand et al.	2021/0137667	A1	5/2021	Sonnette et al.
2017/0113005	A1	4/2017	Linder et al.	2021/0138194	A1	5/2021	Carrison et al.
2017/0143359	A1	5/2017	Nguyen et al.	2021/0186541	A1	6/2021	Thress
2017/0143880	A1	5/2017	Luxon et al.	2021/0205577	A1	7/2021	Jalgaonkar et al.
2017/0143938	A1	5/2017	Ogle et al.	2021/0236148	A1	8/2021	Marchand et al.
2017/0172591	A1	6/2017	Ulm, III	2021/0290925	A1	9/2021	Merritt et al.
2017/0112513	A1	7/2017	Marchand et al.	2021/0315598	A1	10/2021	Buck et al.
2017/0189041	A1	7/2017	Cox et al.	2021/0316127	A1	10/2021	Buck et al.
2017/0196576	A1	7/2017	Long et al.	2021/0330344	A1	10/2021	Rosenbluth et al.
2017/0233908	A1	8/2017	Kroczyński et al.	2021/0378694	A1	12/2021	Thress et al.
2017/0252057	A1	9/2017	Bonnette et al.	2021/0393278	A1	12/2021	O'Malley et al.
2017/0265878	A1	9/2017	Marchand et al.	2021/0404464	A1	12/2021	Patoskie
2017/0281204	A1	10/2017	Garrison et al.	2022/0000505	A1	1/2022	Hauser
2017/0303939	A1	10/2017	Greenhalgh et al.	2022/0000506	A1	1/2022	Hauser
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2017/0303947	A1	10/2017	Greenhalgh et al.	2022/0015798	A1	1/2022	Marchand et al.
2017/0303948	A1	10/2017	Wallace et al.	2022/0022898	A1	1/2022	Cox et al.
2017/0319221	A1*	11/2017	Chu A61B 17/22	2022/0033888	A1	2/2022	Schnall-Levin et al.
2017/0325839	A1	11/2017	Rosenbluth et al.	2022/0039815	A1	2/2022	Thress et al.
2017/0340867	A1	11/2017	Accisano, II	2022/0125451	A1	4/2022	Hauser
2017/0348014	A1	12/2017	Wallace et al.	2022/0142638	A1	5/2022	Enright et al.
2018/0014840	A1	1/2018	Panian	2022/0151647	A1	5/2022	Dolendo et al.
2018/0042623	A1*	2/2018	Batiste A61B 17/22	2022/0152355	A1	5/2022	Dolendo et al.
2018/0042624	A1	2/2018	Greenhalgh et al.	2022/0160381	A1	5/2022	Hauser
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2018/0055999	A1*	3/2018	Bare A61M 1/0281	2022/0160383	A1	5/2022	Hauser
2018/0064453	A1	3/2018	Garrison et al.	2022/0211400	A1	7/2022	Cox et al.
2018/0064454	A1	3/2018	Losordo et al.	2022/0211992	A1	7/2022	Merritt et al.
2018/0070968	A1	3/2018	Wallace et al.	2022/0240959	A1	8/2022	Quick
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2018/0104404	A1	4/2018	Ngo-Chu	2022/0346813	A1	11/2022	Quick
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				2022/0362512	A1	11/2022	Quick et al.
				2022/0370761	A1	11/2022	Quick et al.
				2023/0046775	A1*	2/2023	Quick A61B 17/22
				2023/0059721	A1	2/2023	Chou et al.

(56)

References Cited

U.S. PATENT DOCUMENTS

2023/0062809 A1* 3/2023 Merritt A61F 2/01
 2023/0070120 A1 3/2023 Cox et al.
 2023/0122587 A1 4/2023 Chou et al.
 2023/0200970 A1 6/2023 Merritt et al.
 2023/0218310 A1 7/2023 Scheinblum et al.
 2023/0218313 A1 7/2023 Rosenbluth et al.
 2023/0218383 A1 7/2023 Merritt et al.
 2023/0233311 A1 7/2023 Merritt et al.
 2023/0240705 A1 8/2023 Rosenbluth et al.
 2023/0240706 A1 8/2023 Rosenbluth et al.
 2023/0241302 A1 8/2023 Merritt et al.
 2023/0248380 A1 8/2023 Long et al.
 2023/0270991 A1 8/2023 Merritt et al.
 2023/0310138 A1 10/2023 Merritt et al.
 2023/0310751 A1 10/2023 Merritt et al.
 2023/0320834 A1 10/2023 Merritt et al.
 2023/0329734 A1 10/2023 Marchand et al.
 2023/0338130 A1 10/2023 Merritt et al.
 2023/0338131 A1 10/2023 Merritt et al.
 2023/0355256 A1 11/2023 Dinh
 2023/0355259 A1 11/2023 Marchand et al.
 2023/0355938 A1 11/2023 Merritt et al.
 2023/0363776 A1 11/2023 Quick
 2023/0363883 A1 11/2023 Merritt et al.
 2023/0389932 A1 12/2023 Ozenne et al.
 2023/0390045 A1 12/2023 Merritt et al.
 2024/0058113 A1 2/2024 Strauss et al.
 2024/0074771 A1 3/2024 Quick et al.
 2024/0082540 A1 3/2024 Brodt et al.

FOREIGN PATENT DOCUMENTS

CN 103764049 4/2014
 CN 103932756 7/2014
 CN 104068910 10/2014
 CN 106178227 12/2016
 CN 108348319 7/2018
 CN 110652645 1/2020
 CN 111281482 6/2020
 DE 102017004383 7/2018
 EP 1254634 11/2002
 EP 1867290 2/2013
 EP 2942624 11/2015
 EP 3583972 12/2019
 EP 3589348 1/2020
 EP 3620204 3/2020
 EP 3013404 4/2020
 EP 4137070 2/2023
 GB 1588072 4/1981
 GB 2498349 7/2013
 JP H6190049 7/1994
 JP H07323090 A 12/1995
 JP 2001522631 5/1999
 JP 2004097807 4/2004
 JP 2005-095242 6/2005
 JP 2005230132 9/2005
 JP 2005323702 11/2005
 JP 2006094876 4/2006
 JP 2007-222658 9/2007
 JP 2011526820 1/2010
 WO WO1997017889 5/1997
 WO WO9833443 8/1998
 WO WO9838920 9/1998
 WO WO9839053 9/1998
 WO WO9851237 11/1998
 WO WO1999044542 9/1999
 WO WO0032118 6/2000
 WO WO2000053120 9/2000
 WO WO0202162 1/2002
 WO WO03015840 2/2003
 WO WO2004018916 3/2004
 WO WO2004093696 11/2004
 WO WO2005046736 5/2005
 WO WO2006029270 3/2006
 WO WO2006110186 10/2006

WO WO2006124307 11/2006
 WO WO2007092820 8/2007
 WO WO2009082513 7/2009
 WO WO2009086482 7/2009
 WO WO2009155571 12/2009
 WO WO2010002549 1/2010
 WO WO2010010545 1/2010
 WO WO2010023671 3/2010
 WO WO2010049121 5/2010
 WO WO2010102307 9/2010
 WO WO2011032712 3/2011
 WO WO2011054531 5/2011
 WO WO2011073176 6/2011
 WO WO2012009675 1/2012
 WO WO2012011097 1/2012
 WO WO2012049652 4/2012
 WO WO2012065748 5/2012
 WO WO2012114633 8/2012
 WO WO2012120490 9/2012
 WO WO2012162437 11/2012
 WO WO2014047650 3/2014
 WO WO2014081892 5/2014
 WO WO2015006782 1/2015
 WO WO2015061365 4/2015
 WO WO2015121424 8/2015
 WO WO2015179329 11/2015
 WO WO2015189354 12/2015
 WO WO2015191646 12/2015
 WO WO2016014955 1/2016
 WO WO-2016014955 A1 * 1/2016 A61B 10/025
 WO WO2017024258 2/2017
 WO WO2017058280 4/2017
 WO WO2017070702 4/2017
 WO WO2017106877 6/2017
 WO WO2017189535 11/2017
 WO WO2017189550 11/2017
 WO WO2017189591 11/2017
 WO WO2017189615 11/2017
 WO WO2017210487 12/2017
 WO WO2018049317 3/2018
 WO WO-2018065092 A1 * 4/2018 A61K 35/14
 WO WO2018080590 5/2018
 WO WO2018148174 8/2018
 WO WO2019010318 1/2019
 WO WO2019050765 3/2019
 WO WO2019075444 4/2019
 WO WO2019094456 5/2019
 WO WO2019173475 9/2019
 WO WO2019222117 11/2019
 WO WO2019246240 12/2019
 WO WO2020036809 2/2020
 WO WO2021067134 4/2021
 WO WO2021076954 4/2021
 WO WO2021127202 6/2021
 WO WO2021248042 12/2021
 WO WO2022032173 2/2022
 WO WO2022103848 5/2022
 WO WO2022109021 5/2022
 WO WO2022109034 5/2022
 WO WO2023137341 7/2023
 WO WO2023147353 8/2023
 WO WO2023154612 8/2023
 WO WO2023192925 10/2023
 WO WO2023215779 11/2023

OTHER PUBLICATIONS

Gibbs, et al., "Temporary Stent as a bail-out device during percutaneous transluminal coronary angioplasty: preliminary clinical experience," British Heart Journal, 1994, 71:372-377, Oct. 12, 1993, 6 pgs.
 Gupta, S. et al., "Acute Pulmonary Embolism Advances in Treatment", JAPI, Association of Physicians India, Mar. 2008, vol. 56, 185-191.
 International Search Report and Written Opinion for International App. No. PCT/US13/61470, dated Jan. 17, 2014, 7 pages.
 International Search Report and Written Opinion for International App. No. PCT/US2014/046567, dated Nov. 3, 2014, 13 pages.

(56)

References Cited

OTHER PUBLICATIONS

International Search Report and Written Opinion for International App. No. PCT/US2014/061645, dated Jan. 23, 2015, 15 pages.

International Search Report for International App. No. PCT/US13/71101, dated Mar. 31, 2014, 4 pages.

Konstantinides, S. et al., "Pulmonary embolism hotline 2012—Recent and expected trials", *Thrombosis and Haemostasis*, Jan. 9, 2013:33; 43-50.

Konstantinides, S. et al., "Pulmonary embolism: risk assessment and management", *European Society of Cardiology; European Heart Journal*, Sep. 7, 2012:33, 3014-3022.

Kucher, N. et al., "Percutaneous Catheter Thrombectomy Device for Acute Pulmonary Embolism: In Vitro and in Vivo Testing", *Circulation*, Sep. 2005:112:e28-e32.

Kucher, N., "Catheter Interventions in Massive Pulmonary Embolism", *Cardiology Rounds*, Mar. 2006 vol. 10, Issue 3, 6 pages.

Kucher, N. et al., "Management of Massive Pulmonary Embolism", *Radiology*, Sep. 2005:236:3 852-858.

Kucher, N. et al., "Randomized, Controlled Trial of Ultrasound-Assisted Catheter-Directed Thrombolysis for Acute Intermediate-Risk Pulmonary Embolism." *Circulation*, 2014, 129, pp. 9 pages.

Kuo, W. et al., "Catheter-directed Therapy for the Treatment of Massive Pulmonary Embolism: Systematic Review and Meta-analysis of Modern Techniques", *Journal of Vascular and Interventional Radiology*, Nov. 2009:20:1431-1440.

Kuo, W. et al., "Catheter-Directed Embolectomy, Fragmentation, and Thrombolysis for the Treatment of Massive Pulmonary Embolism After Failure of Systemic Thrombolysis", *American College of CHEST Physicians* 2008: 134:250-254.

Kuo, W. MD, "Endovascular Therapy for Acute Pulmonary Embolism", *Continuing Medical Education Society of Interventional Radiology ("CME"); Journal of Vascular and Interventional Radiology*, Feb. 2012: 23:167-179.

Lee, L. et al., "Massive pulmonary embolism: review of management strategies with a focus on catheter-based techniques", *Expert Rev. Cardiovasc. Ther.* 8(6), 863-873 (2010).

Liu, S. et al., "Massive Pulmonary Embolism: Treatment with the Rotarex Thrombectomy System", *Cardiovascular Interventional Radiology*; 2011: 34:106-113.

Muller-Hulsbeck, S. et al. "Mechanical Thrombectomy of Major and Massive Pulmonary Embolism with Use of the Amplatz Thrombectomy Device", *Investigative Radiology*, Jun. 2001:36:6:317-322.

Reekers, J. et al., "Mechanical Thrombectomy for Early Treatment of Massive Pulmonary Embolism", *CardioVascular and Interventional Radiology*, 2003: 26:246-250.

Schmitz-Rode et al., "New Mesh Basket for Percutaneous Removal of Wall-Adherent Thrombi in Dialysis Shunts," *Cardiovasc Intervent Radiol* 16:7-10 1993 4 pgs.

Schmitz-Rode et al., "Temporary Pulmonary Stent Placement as Emergency Treatment of Pulmonary Embolism," *Journal of the American College of Cardiology*, vol. 48, No. 4, 2006 (5 pgs.).

Schmitz-Rode, T. et al., "Massive Pulmonary Embolism: Percutaneous Emergency Treatment by Pigtail Rotation Catheter", *JACC Journal of the American College of Cardiology*, Aug. 2000:36:2:375-380.

Spiotta, A et al., "Evolution of thrombectomy approaches and devices for acute stroke: a technical review." *J NeuroIntervent Surg* 2015, 7, pp. 7 pages.

Svilaas, T. et al., "Thrombus Aspiration During Primary Percutaneous Coronary Intervention." *The New England Journal of Medicine*, 2008, vol. 358, No. 6, 11 pages.

Tapson, V., "Acute Pulmonary Embolism", *The New England Journal of Medicine*, Mar. 6, 2008:358:2037-52.

The Penumbra Pivotal Stroke Trial Investigators, "The Penumbra Pivotal Stroke Trial: Safety and Effectiveness of a New Generation of Mechanical Devices for Clot Removal in Intracranial Large Vessel Occlusive Disease." *Stroke*, 2009, 40: pp. 9 pages.

Truong et al., "Mechanical Thrombectomy of Iliocaval Thrombosis Using a Protective Expandable Sheath," *Cardiovasc Intervent Radiol* 27:254-258, 2004, 5 pgs.

Turk et al., "ADAPT FAST study: a direct aspiration first pass technique for acute stroke thrombectomy." *J NeuroIntervent Surg*, vol. 6, 2014, 6 pages.

Uflacker, R., "Interventional Therapy for Pulmonary Embolism", *Journal of Vascular and Interventional Radiology*, Feb. 2001: 12:147-164.

Verma, R., MD et al. "Evaluation of a Newly Developed Percutaneous Thrombectomy Basket Device in Sheep With Central Pulmonary Embolisms", *Investigative Radiology*, Oct. 2006, 41, 729-734.

International Search Report and Written Opinion for International App. No. PCT/US2015/034987 filed Jun. 9, 2015, Applicant: Inceptus Medical, LLC, dated Sep. 17, 2015, 12 pages.

International Search Report and Written Opinion for International App. No. PCT/US2016/067628 filed Dec. 19, 2016, Applicant: Inari Medical, Inc., dated Apr. 10, 2017, 11 pages.

Goldhaber, S. et al. "Percutaneous Mechanical Thrombectomy for Acute Pulmonary Embolism—A Double-Edged Sword," *American College of CHEST Physicians*, Aug. 2007, 132:2, 363-372.

Goldhaber, S., "Advanced treatment strategies for acute pulmonary embolism, including thrombolysis and embolectomy," *Journal of Thrombosis and Haemostasis*, 2009: 7 (Suppl. 1): 322-327.

International Search Report and Written Opinion for International App. No. PCT/US2017/029696, Date of Filing: Apr. 26, 2017, Applicant: Inari Medical, Inc., dated Sep. 15, 2017, 19 pages.

International Search Report and Written Opinion for International App. No. PCT/US2016/058536, Date of Filing: Oct. 24, 2016, Applicant: Inari Medical, Inc., dated Mar. 13, 2017, 14 pages.

International Search Report and Written Opinion for International App. No. PCT/US2018/048786, Date of Filing: Aug. 30, 2018, Applicant: Inari Medical, Inc., dated Dec. 13, 2018, 12 pages.

International Search Report and Written Opinion for International App. No. PCT/US2018/055780, Date of Filing: Oct. 13, 2018, Applicant: Inceptus Medical LLC., dated Jan. 22, 2019, 8 pages.

International Search Report and Written Opinion for International App. No. PCT/US2019/045794, Date of Filing: Aug. 8, 2019, Applicant: Inari Medical, Inc., dated Nov. 1, 2019, 17 pages.

International Search Report and Written Opinion for International App. No. PCT/US2020/056067, Date of Filing: Oct. 16, 2020; Applicant: Inari Medical, Inc., dated Jan. 22, 2021, 8 pages.

International Search Report and Written Opinion for International App. No. PCT/US2020/055645, Date of Filing: Dec. 17, 2020; Applicant: Inari Medical, Inc., dated Apr. 14, 2021, 12 pages.

Vorwerk, D. MD, et al., "Use of a Temporary Caval Filter to Assist Percutaneous Iliocaval Thrombectomy: Experimental Results." *SCVIR*, 1995, 4 pages.

Wikipedia; Embolectomy; retrieved from the internet: <https://en.wikipedia.org/wiki/Embolectomy>; 4 pgs.; retrieved/printed: Mar. 24, 2016.

O'Sullivan; Thrombolysis versus thrombectomy in acute deep vein thrombosis; *Interventional Cardiology*; 3(5); pp. 589-596; Oct. 2011.

Capture Vascular Systems; (company website); retrieved from the internet: <http://www.capturevascular.com>; 3 pgs.; retrieved/printed: Mar. 24, 2016.

Edwards Lifesciences; Fogarty® Occlusion Catheters (product brochure); retrieved from the internet: <http://web.archive.org/web/20150228193218/http://www.edwards.com/products/vascular/atraumaticocclusion/pages/occlusioncatheter.aspx>; © 2011; 2 pgs.; retrieved/printed: Mar. 24, 2011.

Boston Scientific; Fetch(TM) 2 Aspiration Catheter (product information); retrieved from the internet: <http://www.bostonscientific.com/en-US/products/thrombectomy-systems/fetch2-aspiration-catheter.html>; 2 pgs.; retrieved/printed: Mar. 24, 2016.

Penumbra, Inc.; Indigo® System (product information); retrieved from the internet: <http://www.penumbrainc.com/peripheralpercutaneous-thromboembolectomy/indigo-system>; 7 pgs.; retrieved/printed: Mar. 24, 2016.

Youtube; Merci Retrieval System X Series Animation; uploaded Mar. 16, 2009 (product information); posted on May 7, 2009 by

(56)

References Cited

OTHER PUBLICATIONS

SSMDePAUL, time 1:09, retrieved from the internet: <https://www.youtube.com/watch?v=MGX7deuFkhc>; 3 pgs.; retrieved/printed: Mar. 24, 2016.

Covidien; Solitaire(TM) AS Neurovascular Remodeling Device (product information); retrieved from the internet: <http://www.ev3.net/neuro/intl/remodeling-devices/solitaire-ab.htm>; © 2015; 2 pgs.; retrieved/printed: Mar. 24, 2016.

International Search Report and Written Opinion for International App. No. PCT/US21/35965, Date of Filing: Jun. 4, 2021, Applicant: Inari Medical, Inc., dated Sep. 28, 2021, 12 pages.

International Search Report and Written Opinion for International App. No. PCT/US21/45072 Date of Filing: Aug. 6, 2021, Applicant: Inari Medical, Inc., dated Jan. 20, 2022, 10 pages.

International Search Report and Written Opinion for International App. No. PCT/US21/58793; Date of Filing: Nov. 10, 2021, Applicant: Inari Medical, Inc., dated Mar. 16, 2022, 13 pages.

International Search Report and Written Opinion for International App. No. PCT/US21/59718; Date of Filing: Nov. 17, 2021, Applicant: Inari Medical, Inc., dated Mar. 22, 2022, 13 pages.

International Search Report and Written Opinion for International App. No. PCT/US21/59735; Date of Filing: Nov. 17, 2021, Applicant: Inari Medical, Inc., dated Mar. 22, 2022, 11 pages.

International Search Report and Written Opinion for International App. No. PCT/US23/60502; Date of Filing: Jan. 11, 2023, Applicant: Inari Medical, Inc., dated May 25, 2023, 9 pages.

International Search Report and Written Opinion for International App. No. PCT/US23/61256; Date of Filing: Jan. 25, 2023, Applicant: Inari Medical, Inc., dated Jun. 7, 2023, 8 pages.

Gross et al., "Dump the pump: manual aspiration thrombectomy (MAT) with a syringe is technically effective, expeditious, and cost-efficient," J NeuroIntervent Surg, 2018, 4 pages.

International Search Report and Written Opinion for International App. No. PCT/US23/60927; Date of Filing: Jan. 19, 2023, Applicant: Inari Medical, Inc., dated Jul. 20, 2023, 12 pages.

Extended European Search Report issued for EP Application No. 20877370.5, Date of Mailing: Oct. 17, 2023, 11 pages.

International Search Report and Written Opinion for International App. No. PCT/US23/65128; Date of Filing: Mar. 30, 2023, Applicant: Inari Medical, Inc., Date of Mailing: Nov. 14, 2023, 14 pages.

English translation of Japanese Office Action received for JP Application No. 2022-574456, Applicant: Inari Medical, Inc, Date of Mailing: Jan. 23, 2024, 12 pages.

Chinese First Office Action received for CN Application No. 201980067623.1, Applicant: Inari Medical, Inc., Date of Mailing: Jan. 31, 2024, 10 pages.

International Search Report and Written Opinion for International App. No. PCT/US23/73765; Date of Filing: Sep. 8, 2023, Applicant: Inari Medical, Inc., Date of Mailing: Feb. 28, 2024, 7 pages.

International Search Report and Written Opinion for International App. No. PCT/US23/69892; Date of Filing: Jul. 10, 2023, Applicant: Inari Medical, Inc., Date of Mailing: Feb. 29, 2024, 12 pages.

English translation of Japanese Office Action mailed Jan. 19, 2024 for Japanese Application No. 2022- 160947, 8 pages.

International Search Report and Written Opinion for International App. No. PCT/US23/66538; Date of Filing: May 3, 2023, Applicant: Inari Medical, Inc., Date of Mailing: Jan. 4, 2024, 14 pages.

* cited by examiner

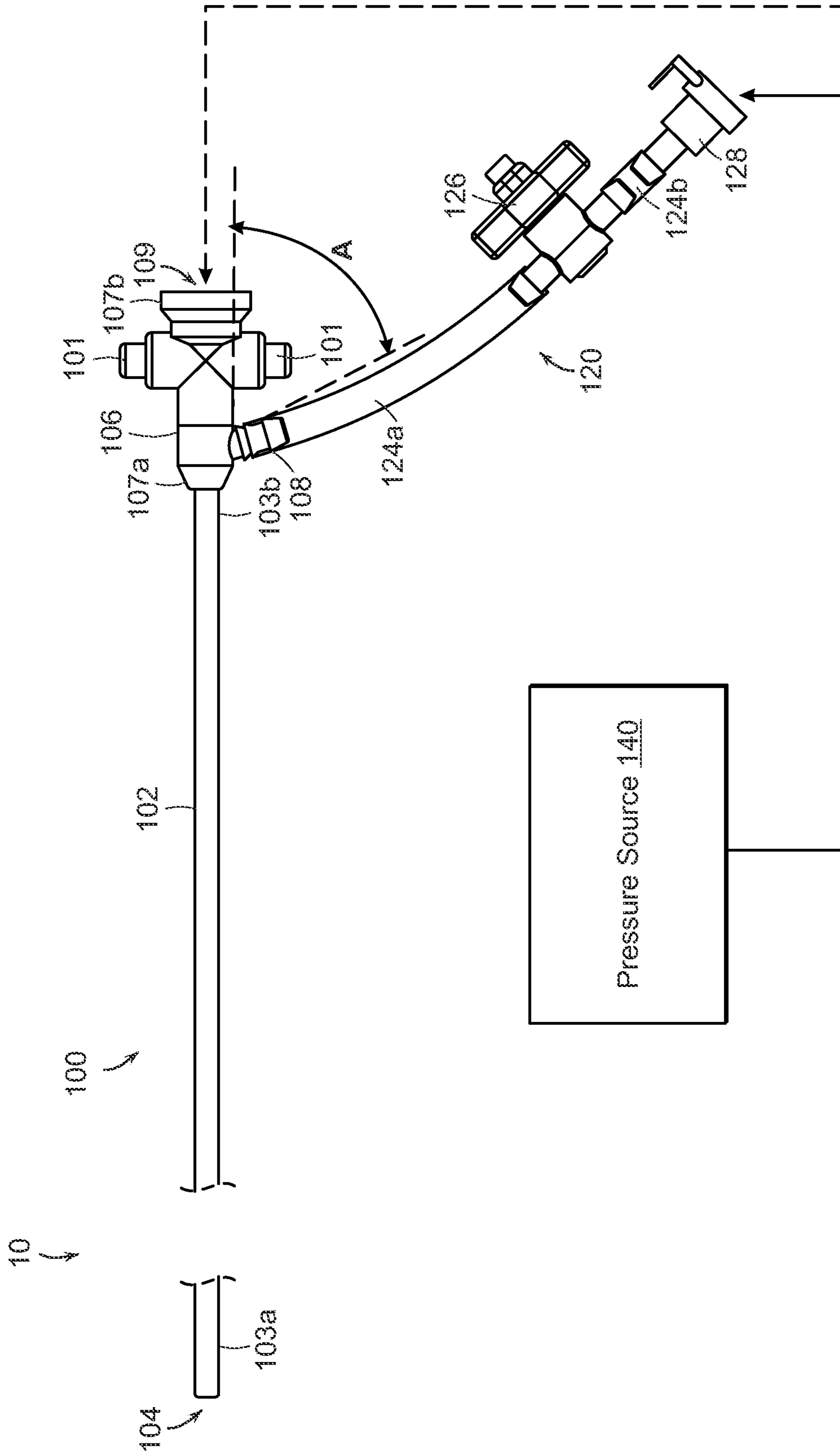


FIG. 1

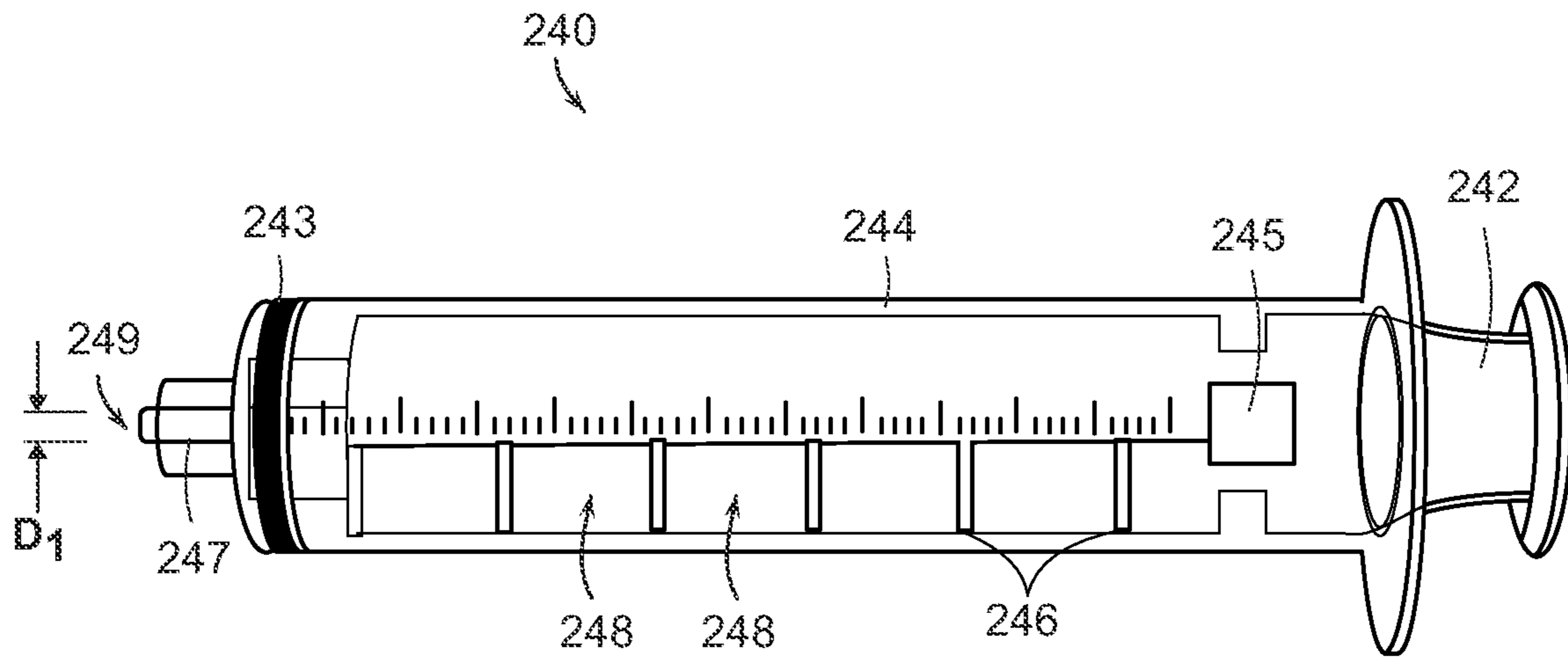


FIG. 2

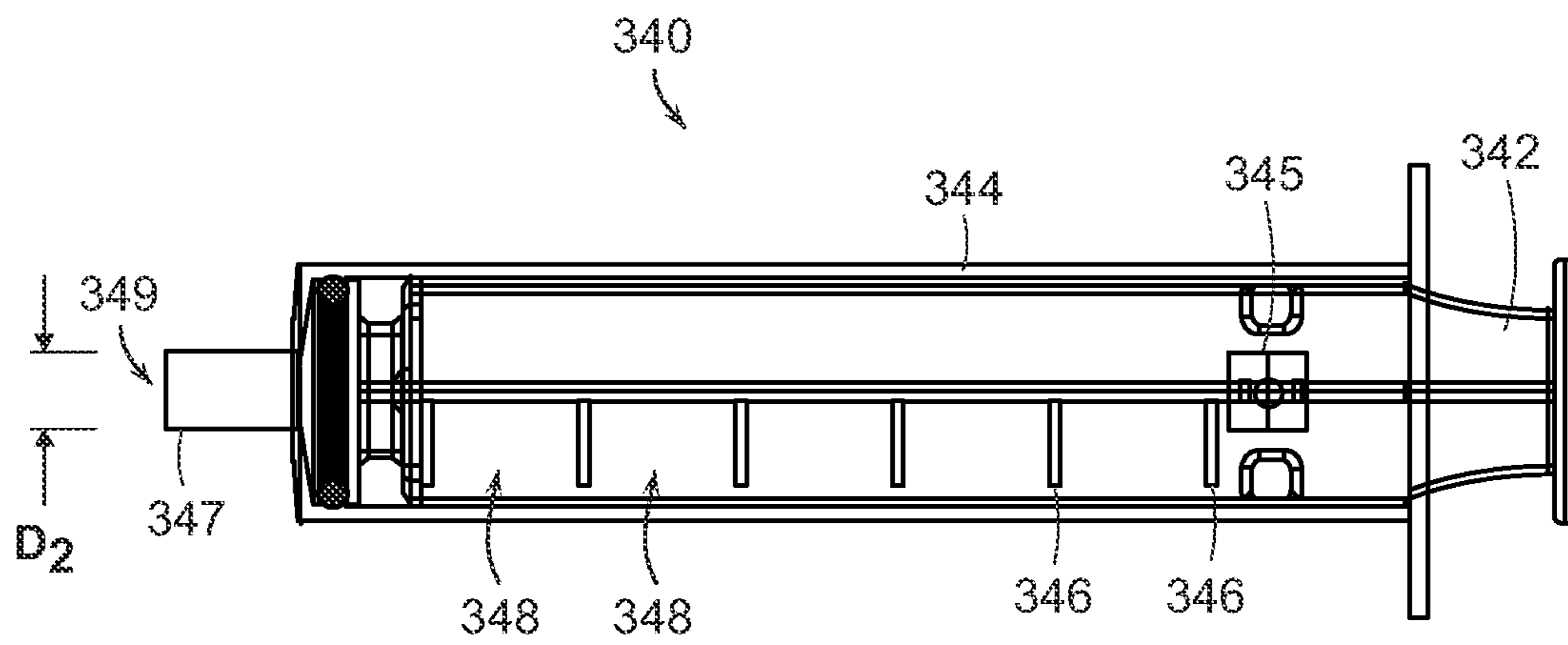


FIG. 3A

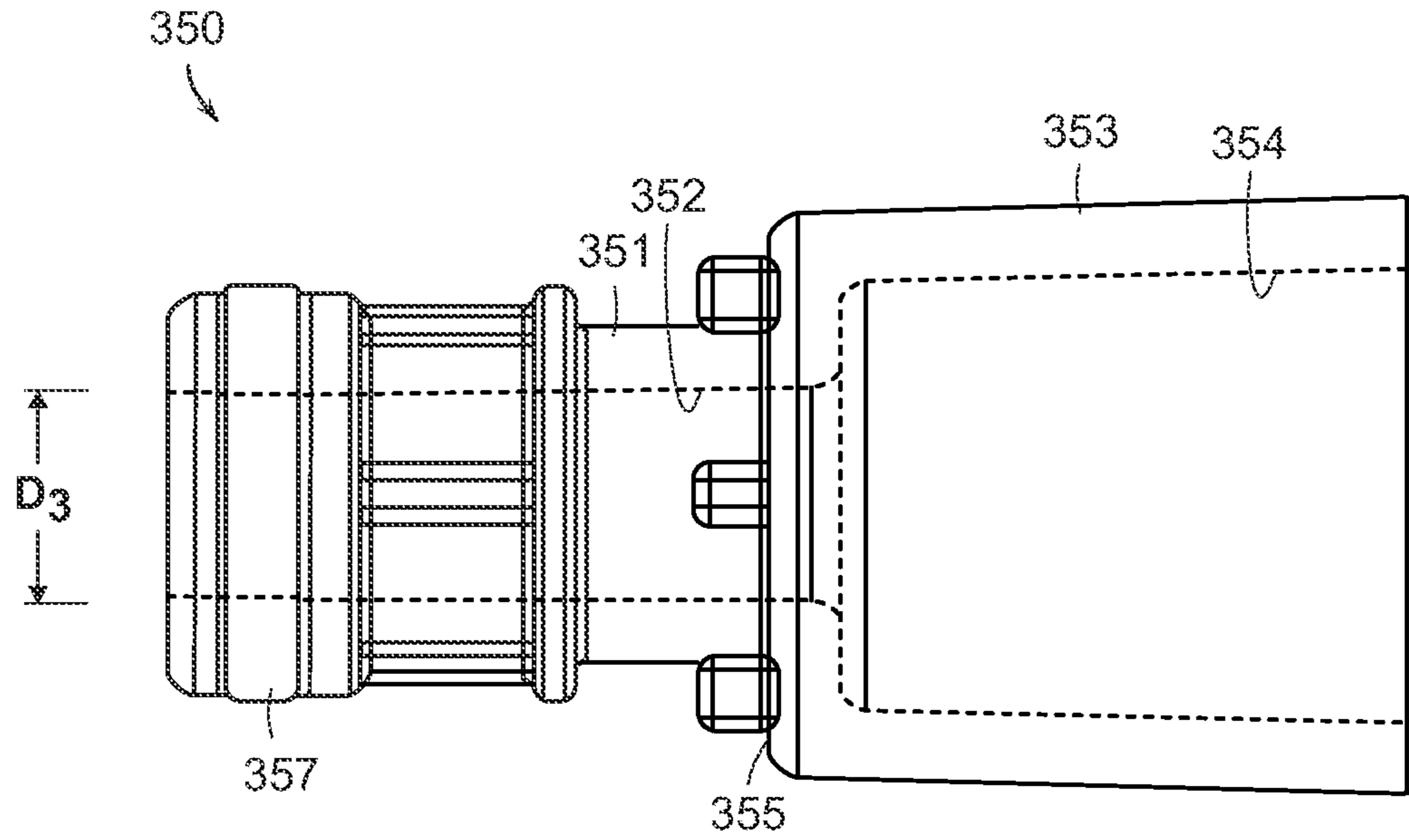


FIG. 3B

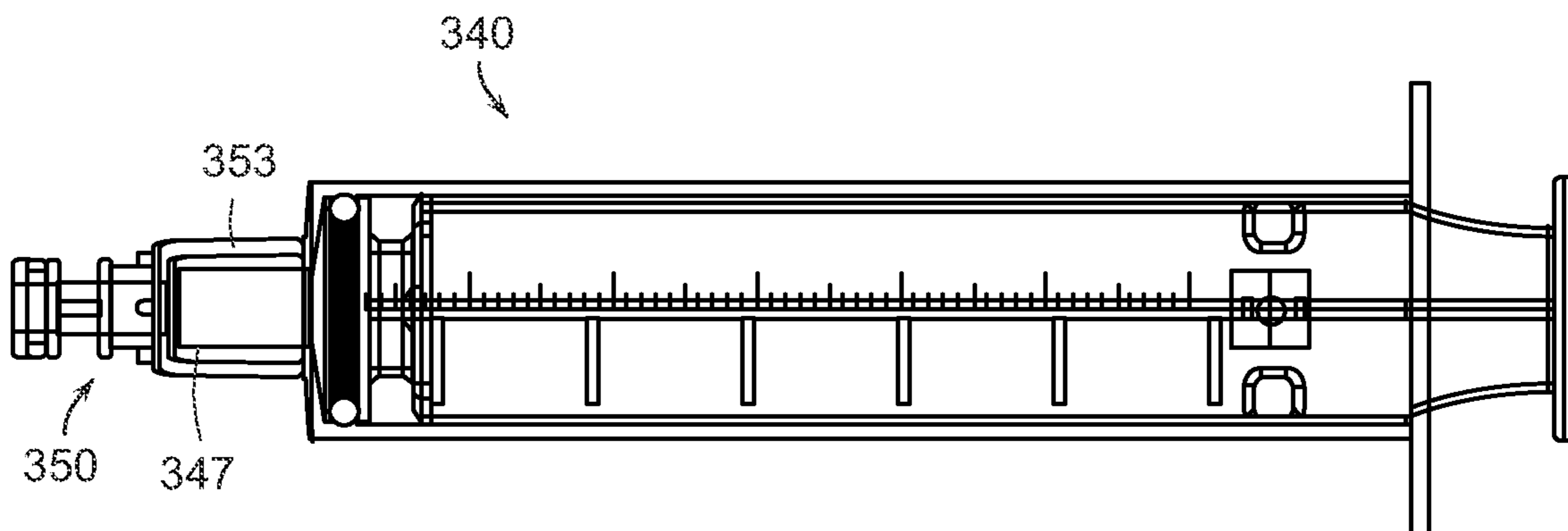


FIG. 3C

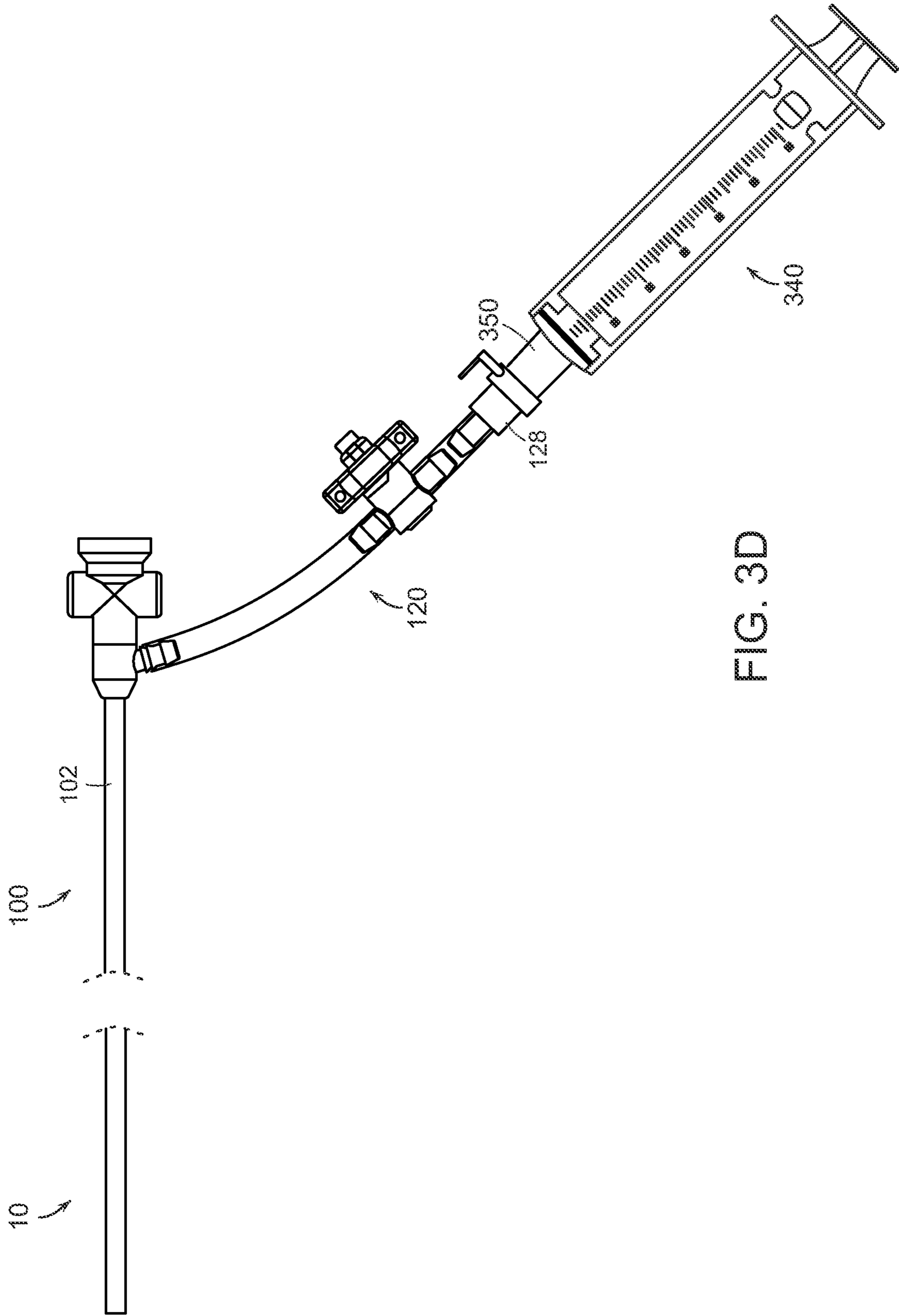
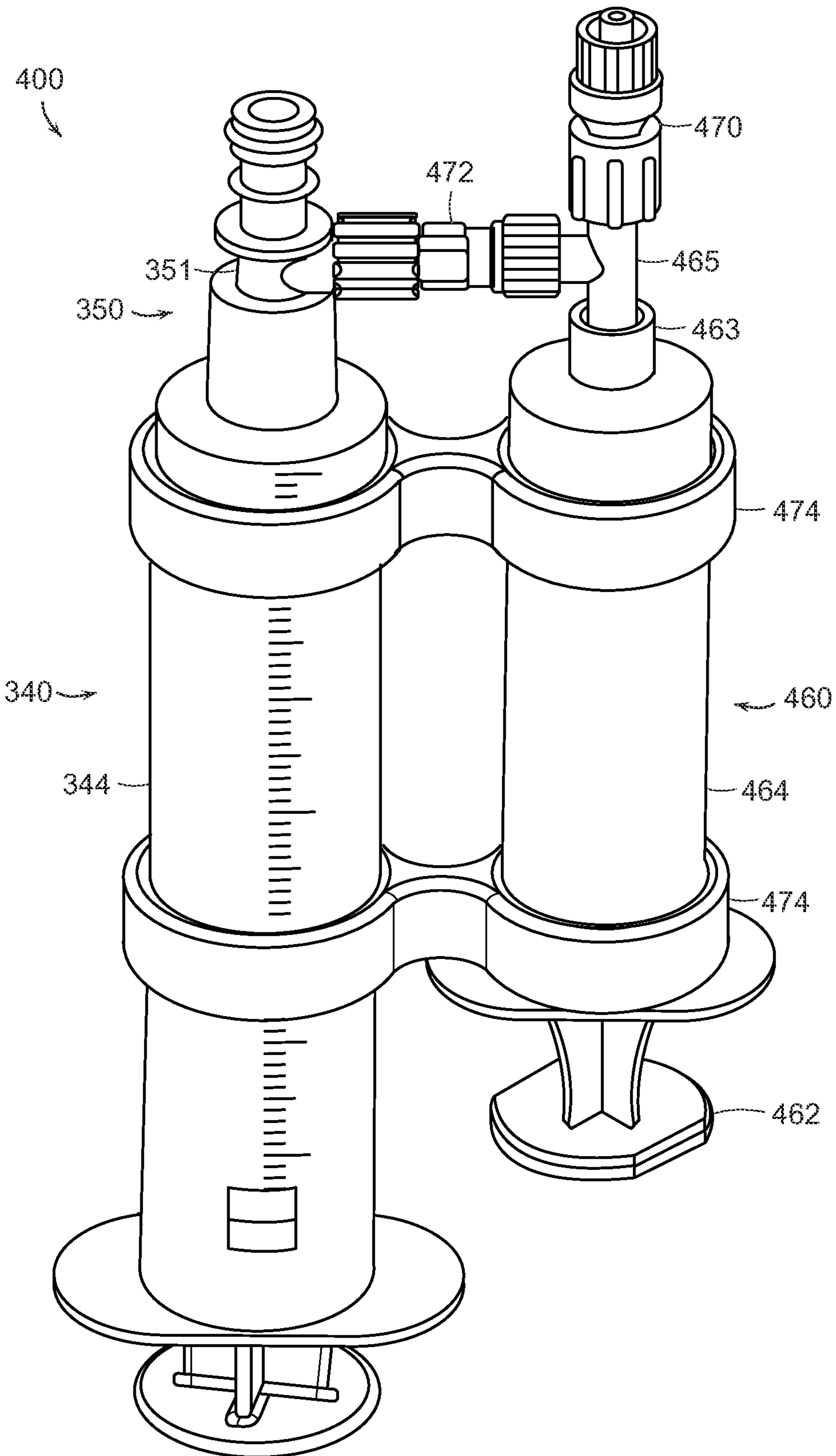


FIG. 3D

FIG. 4A



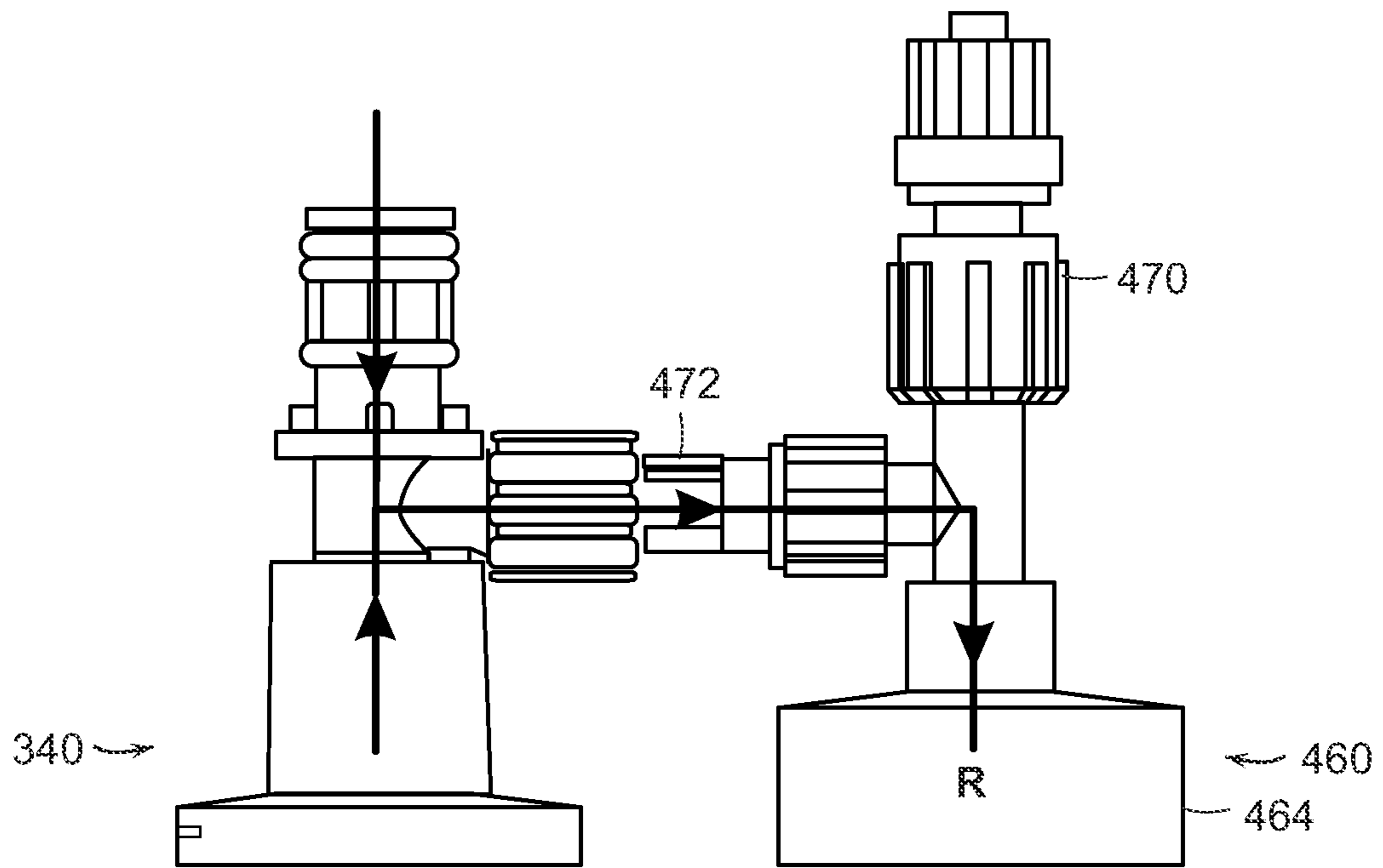


FIG. 4B

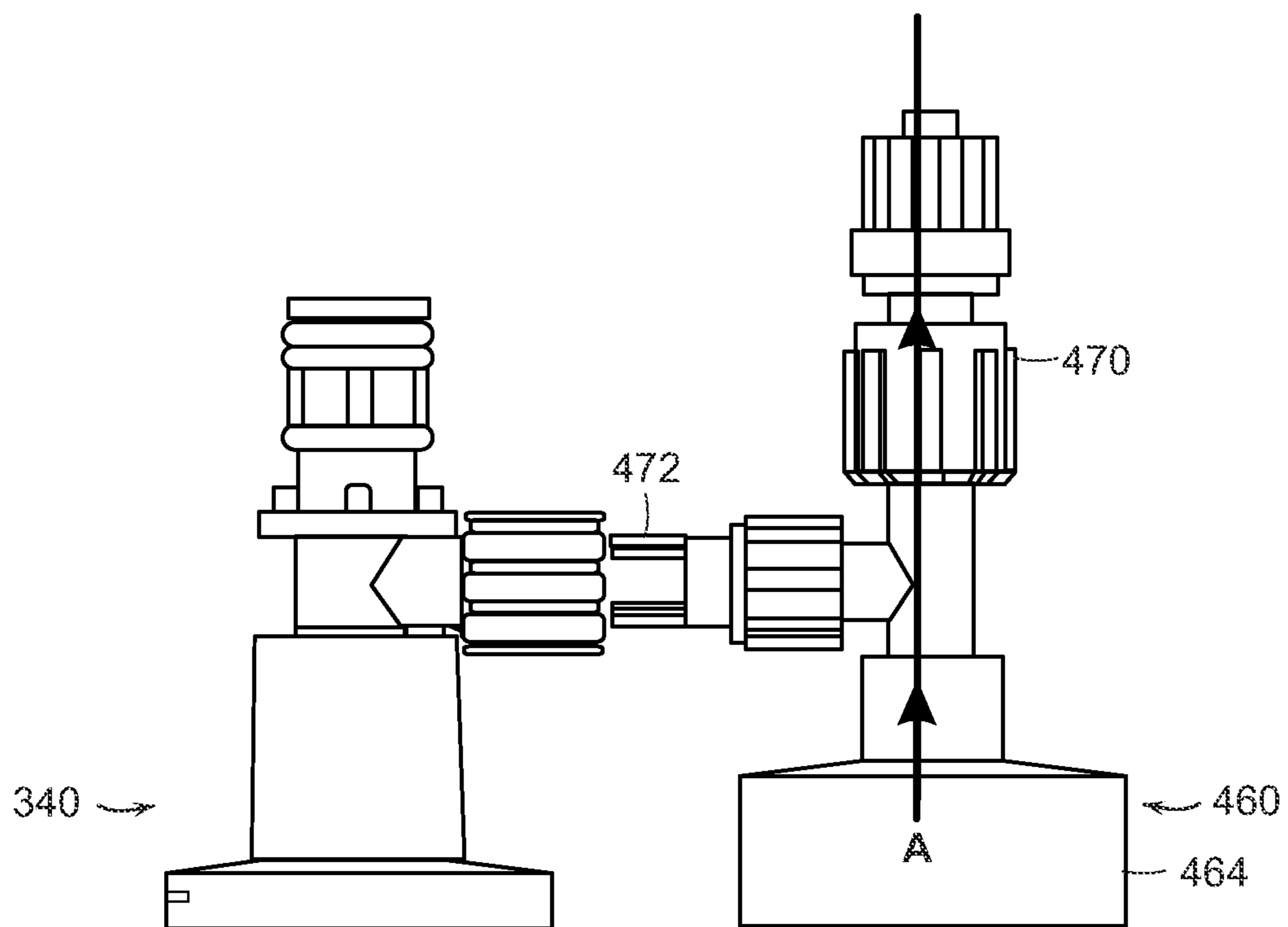


FIG. 4C

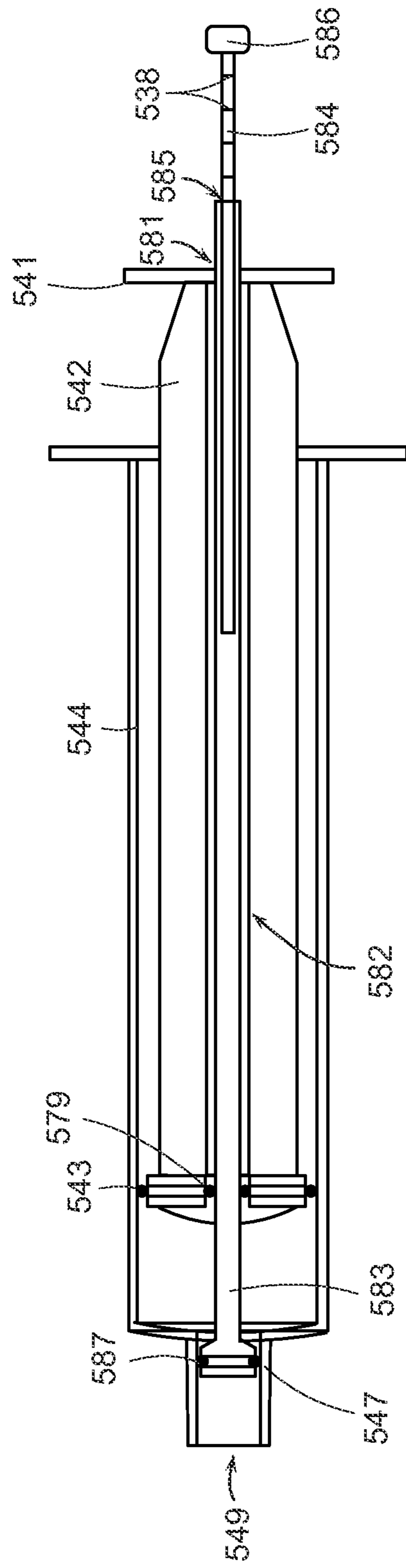


FIG. 5

FIG. 6

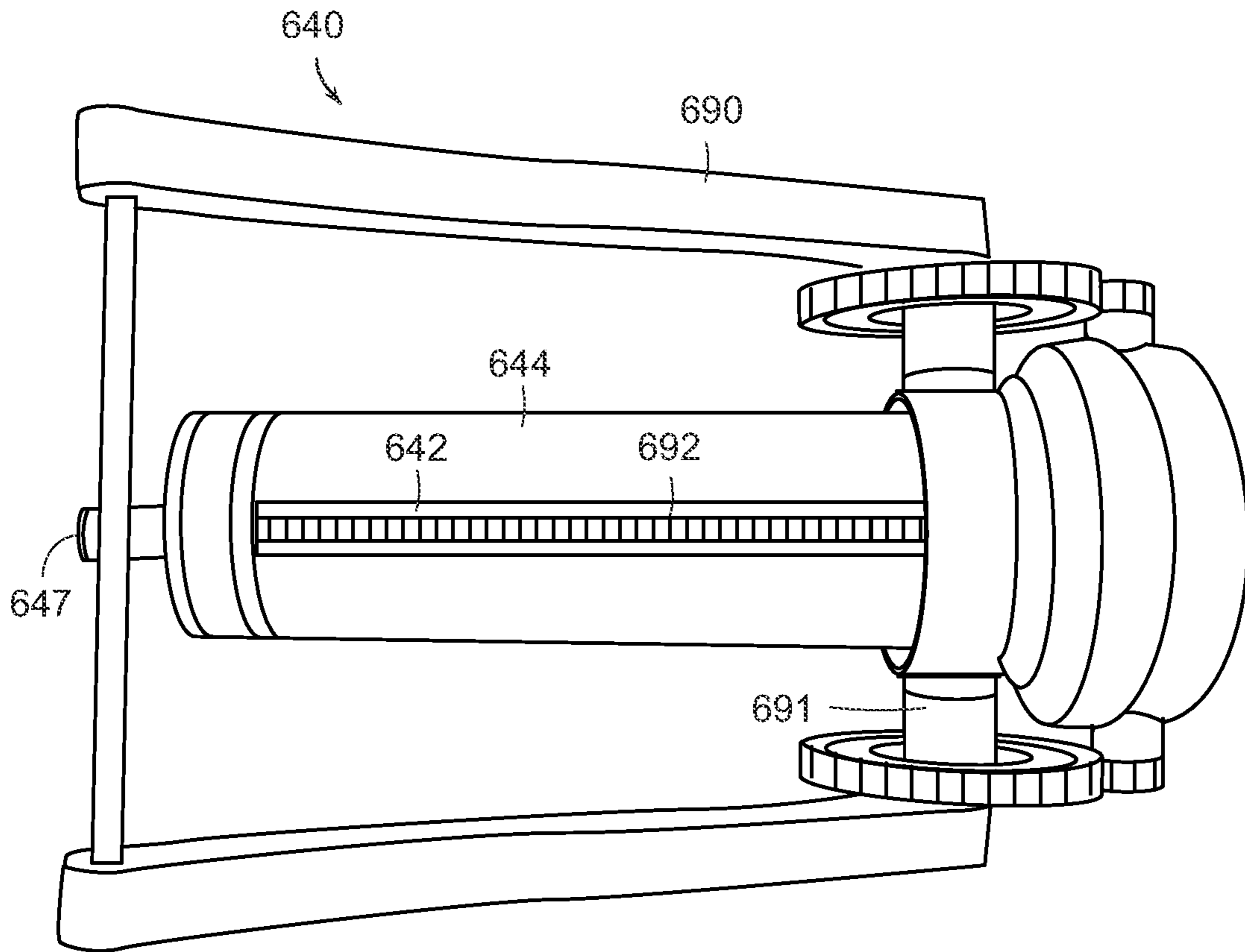
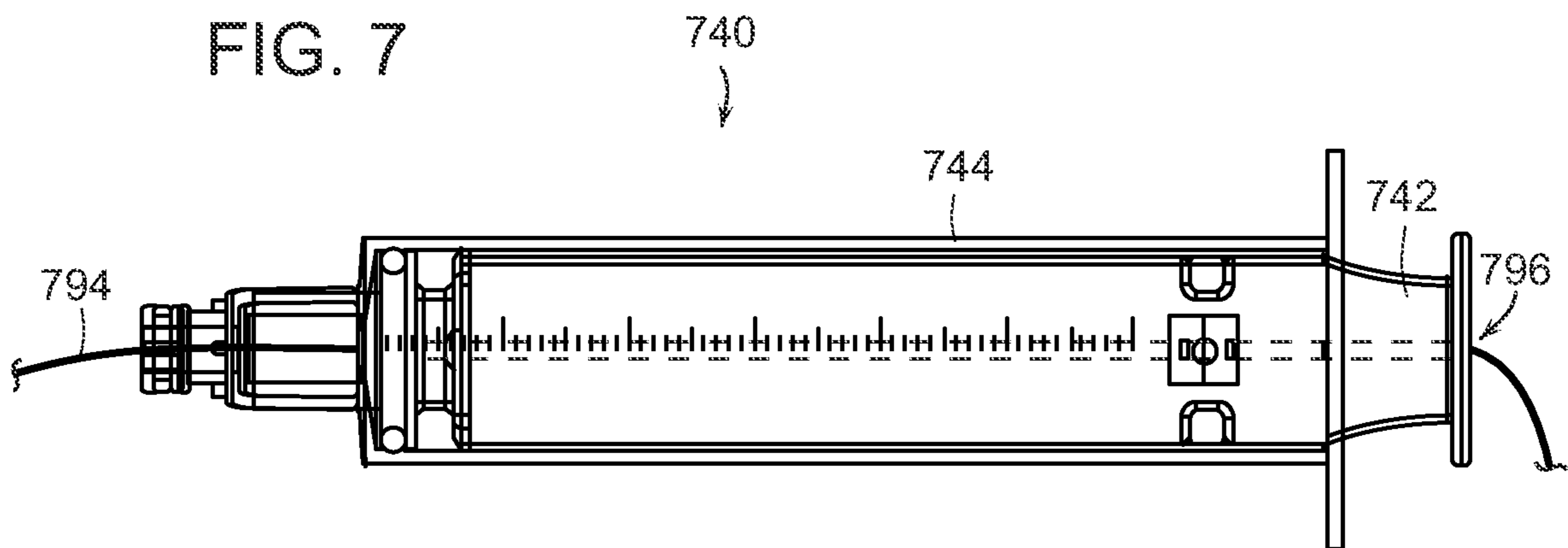


FIG. 7



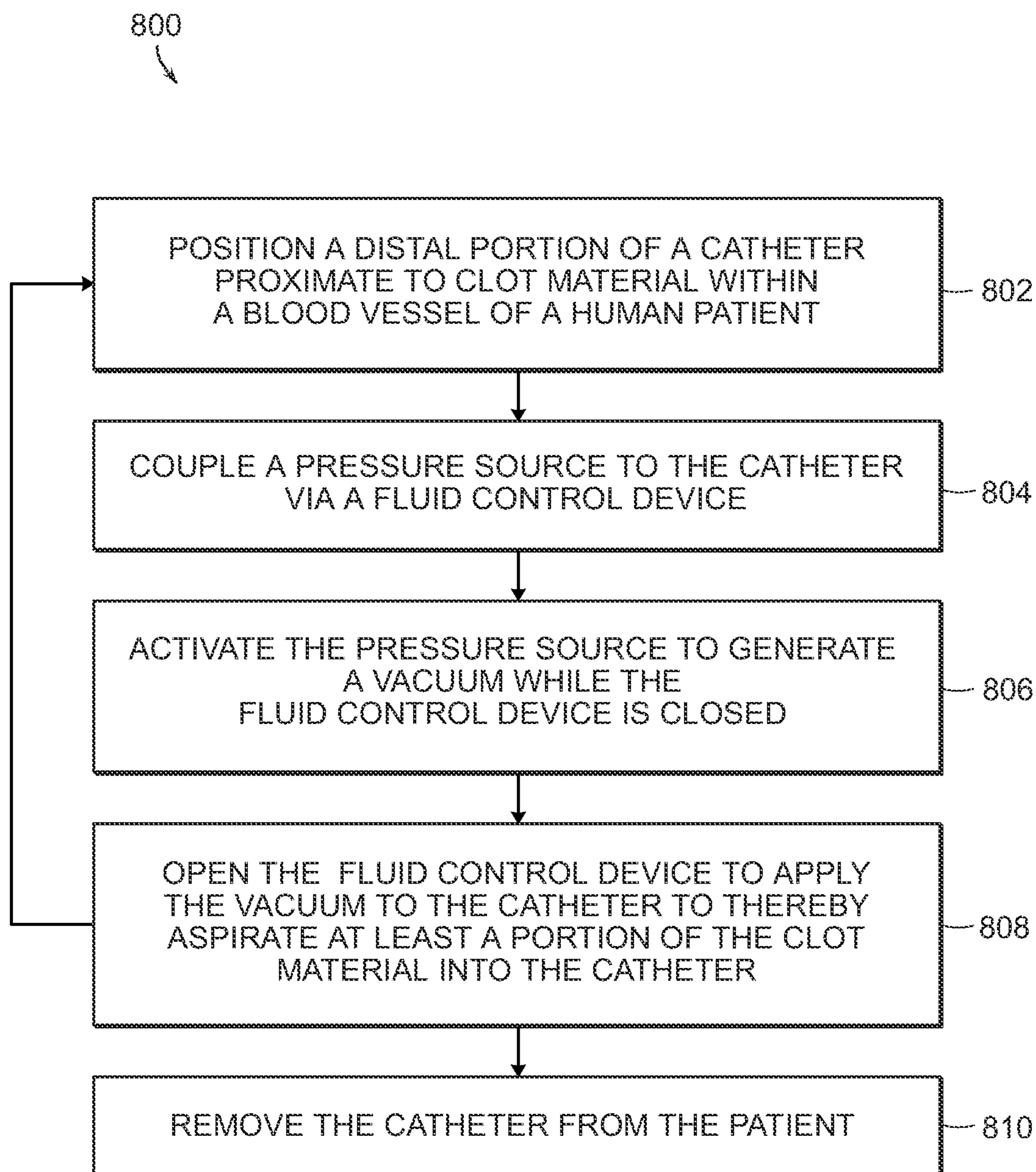


FIG. 8

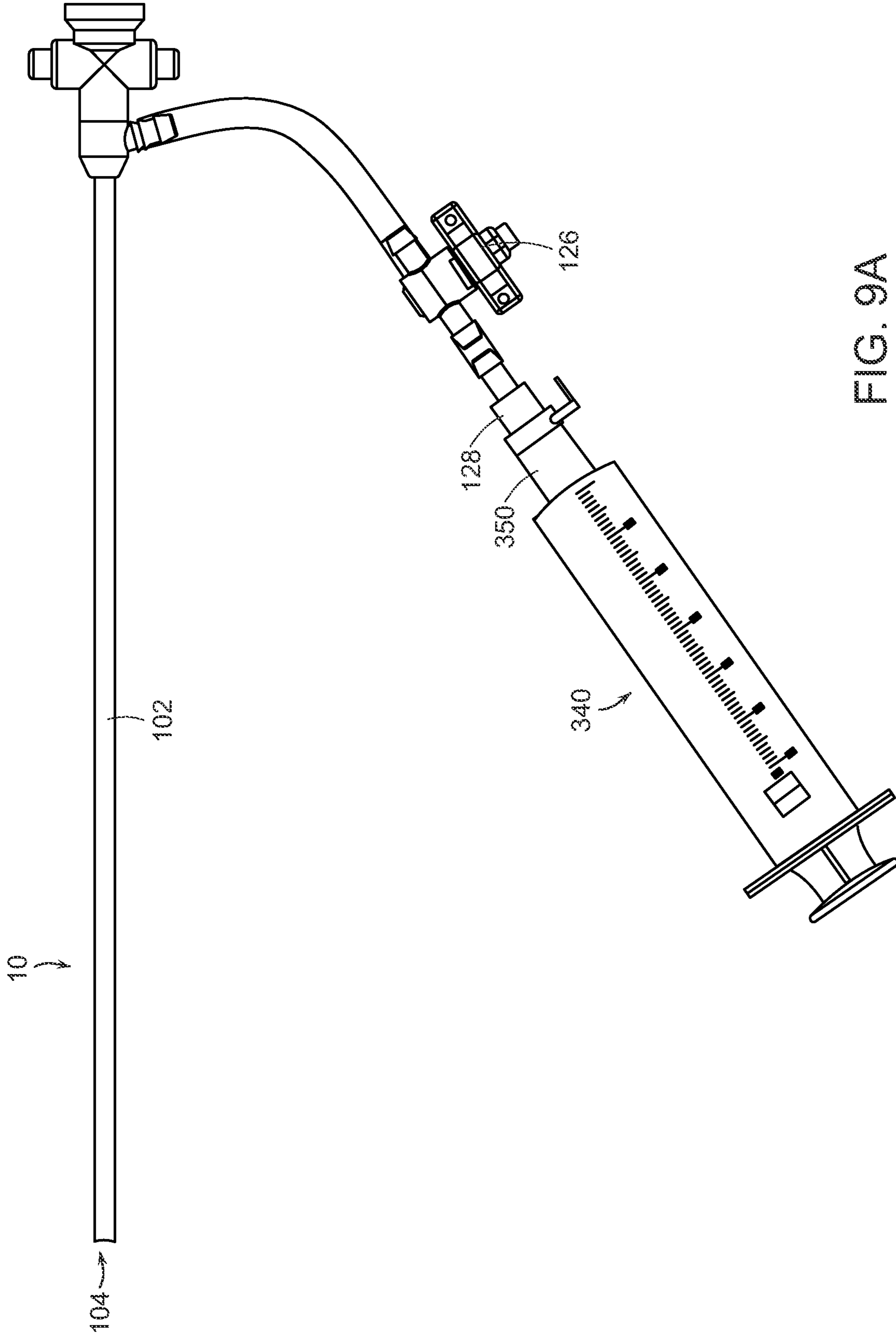


FIG. 9A

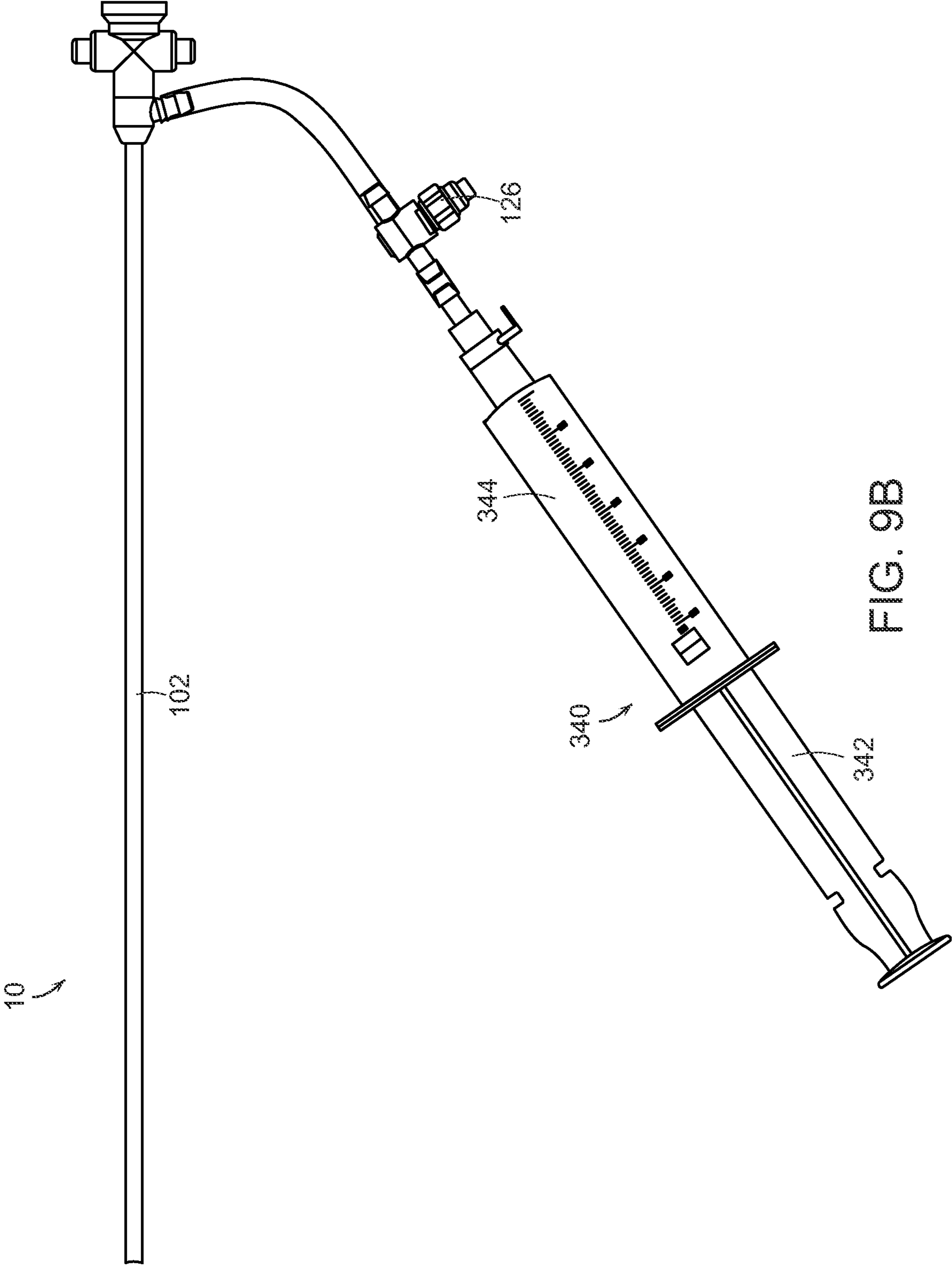
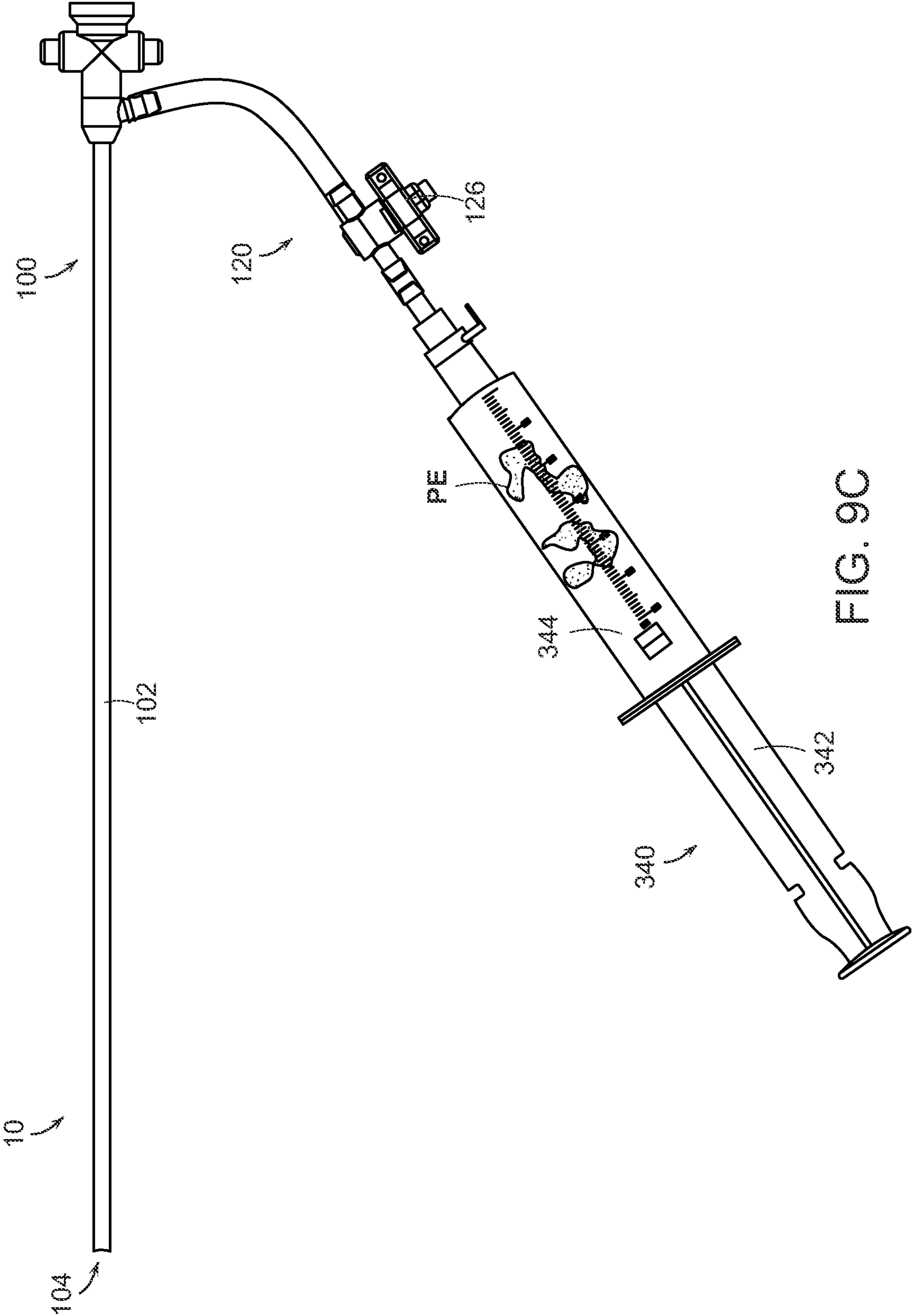


FIG. 9B



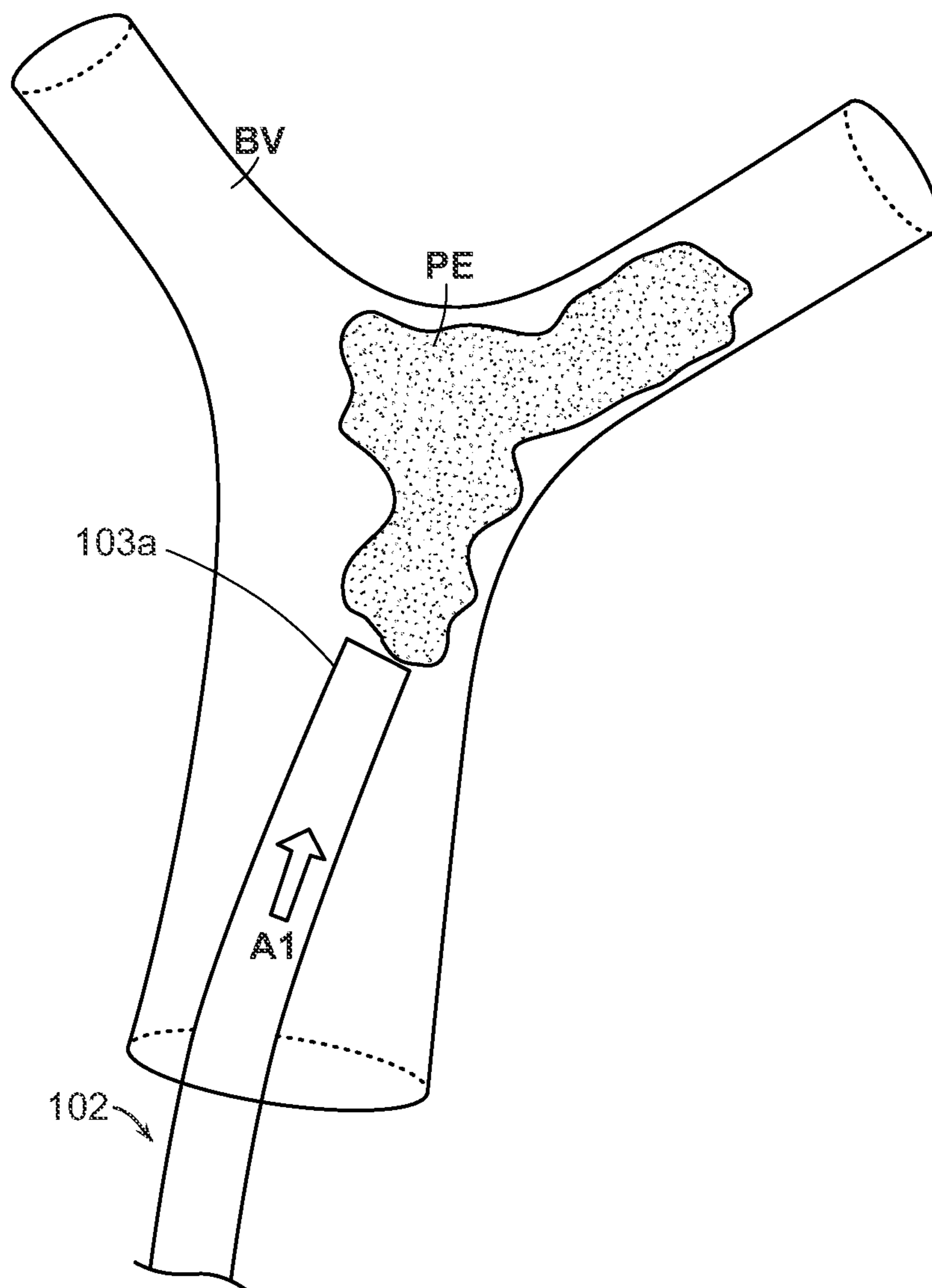


FIG. 10A

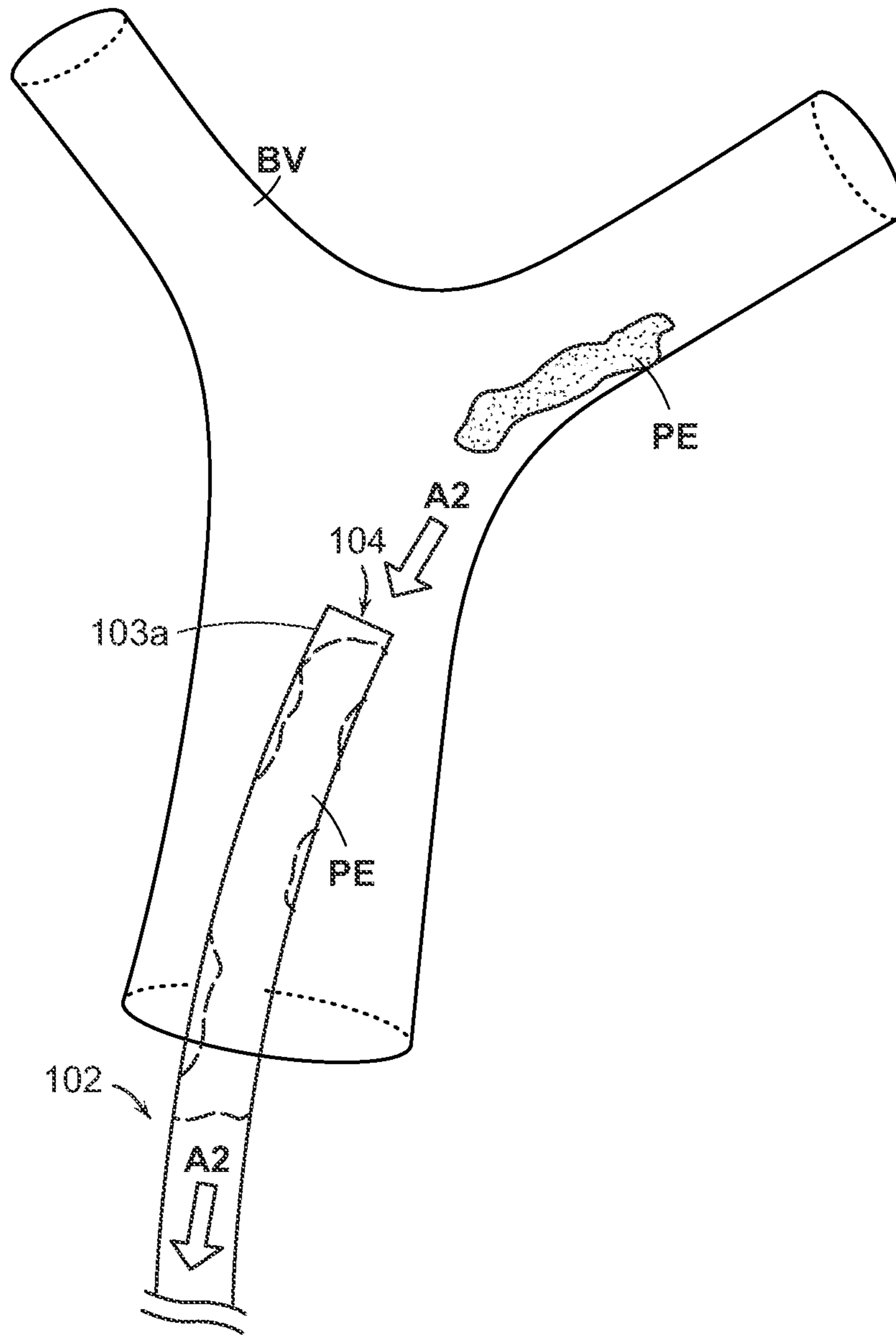


FIG. 10B

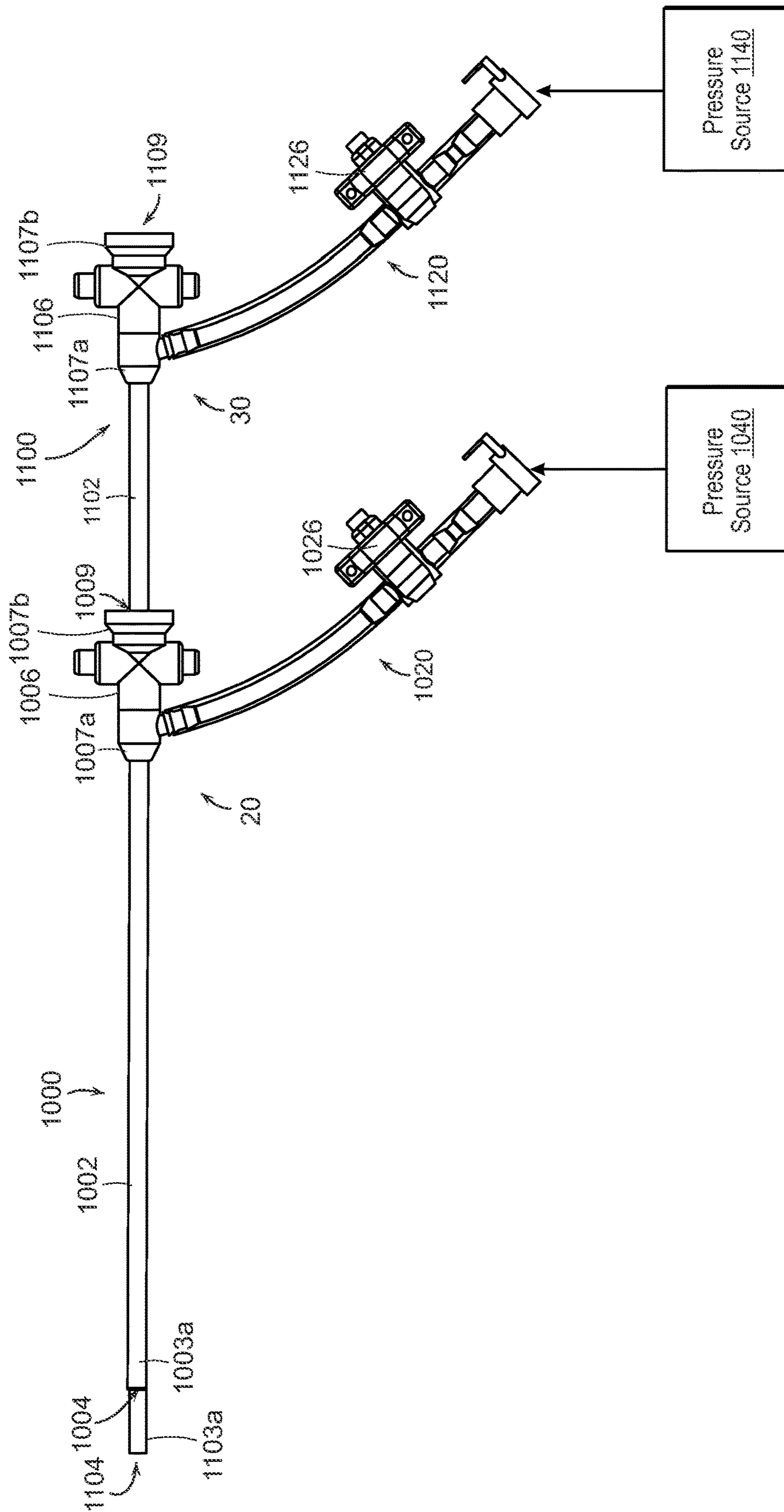
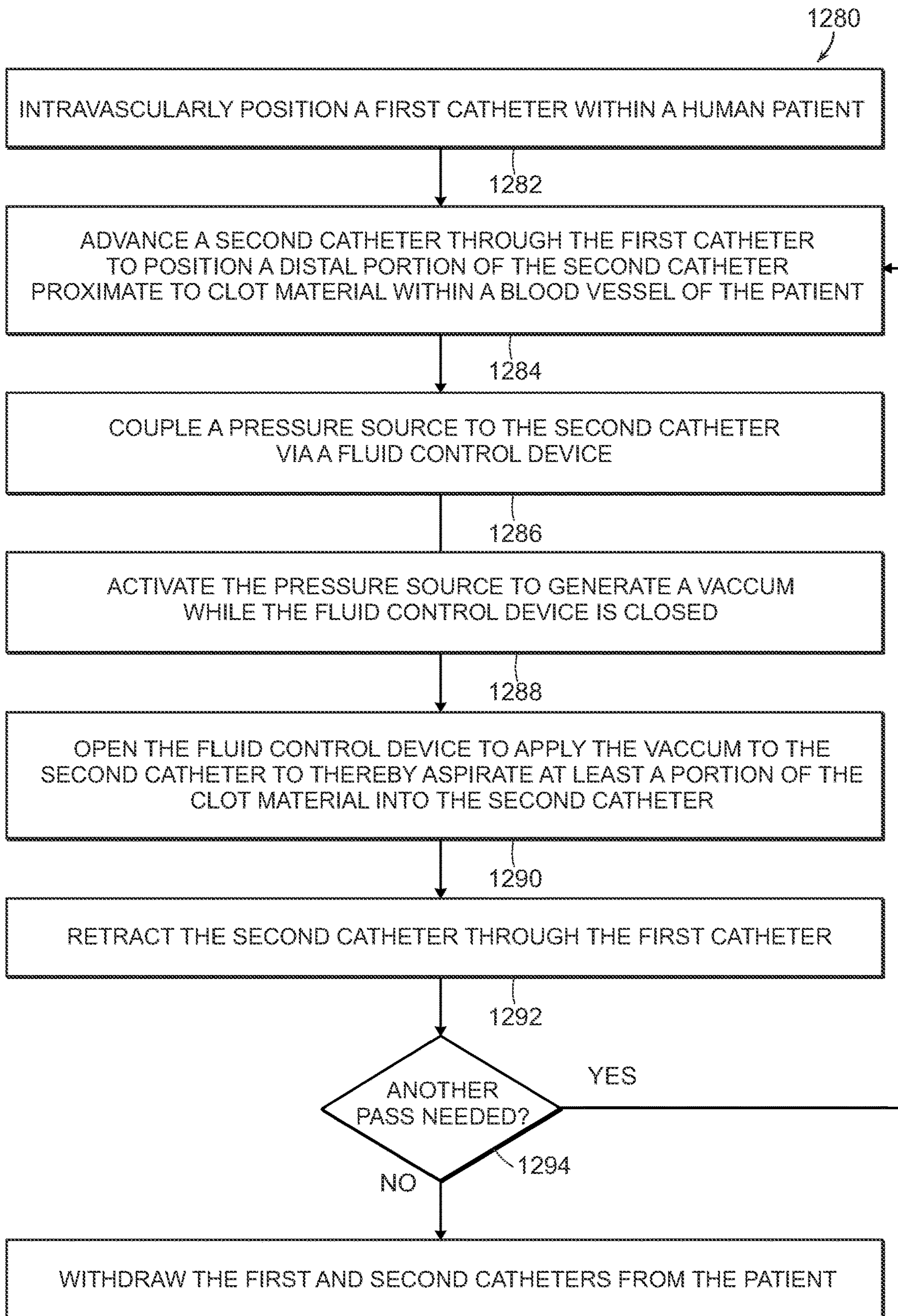


FIG. 11



1296 FIG. 12

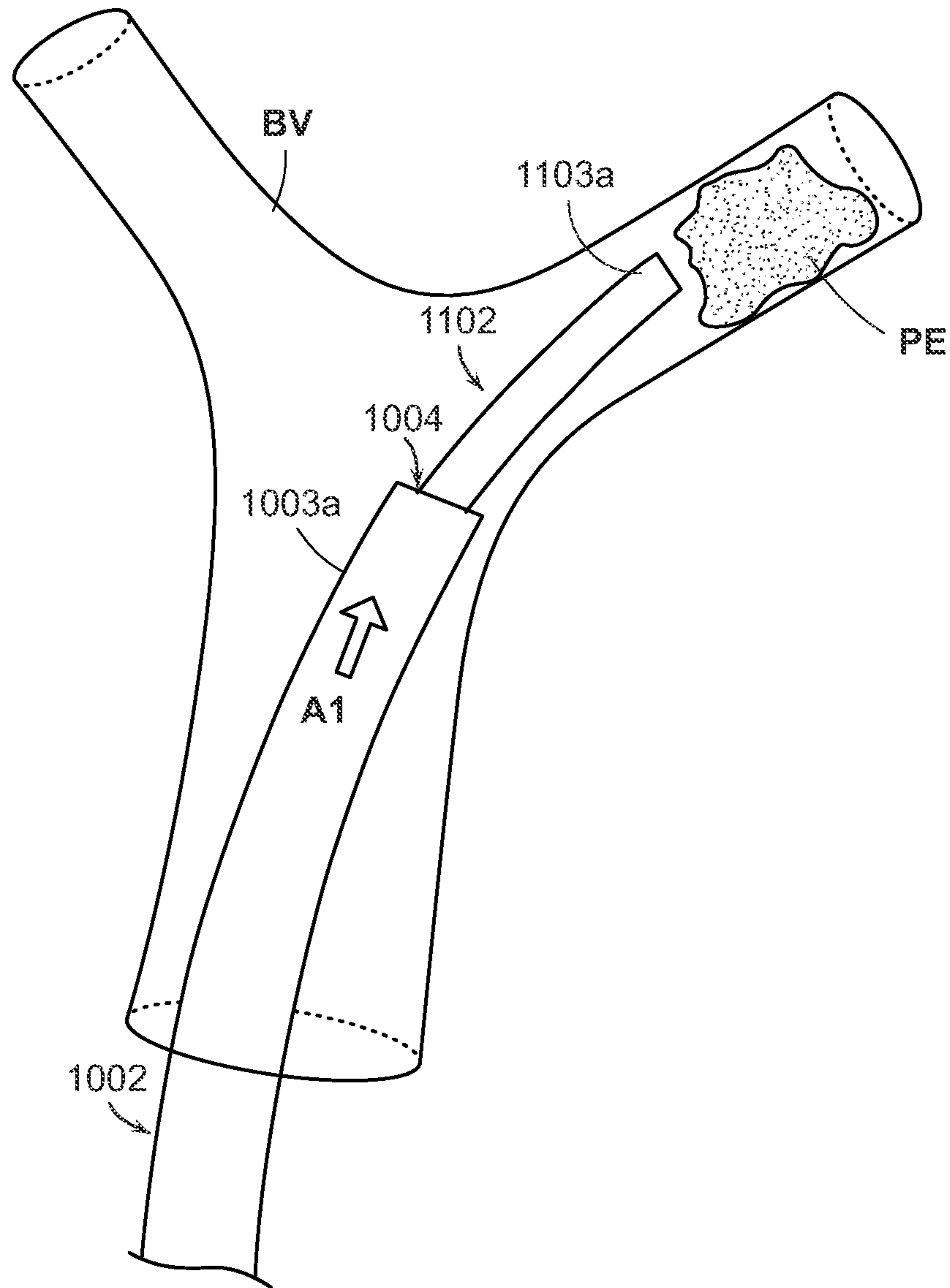


FIG. 13A

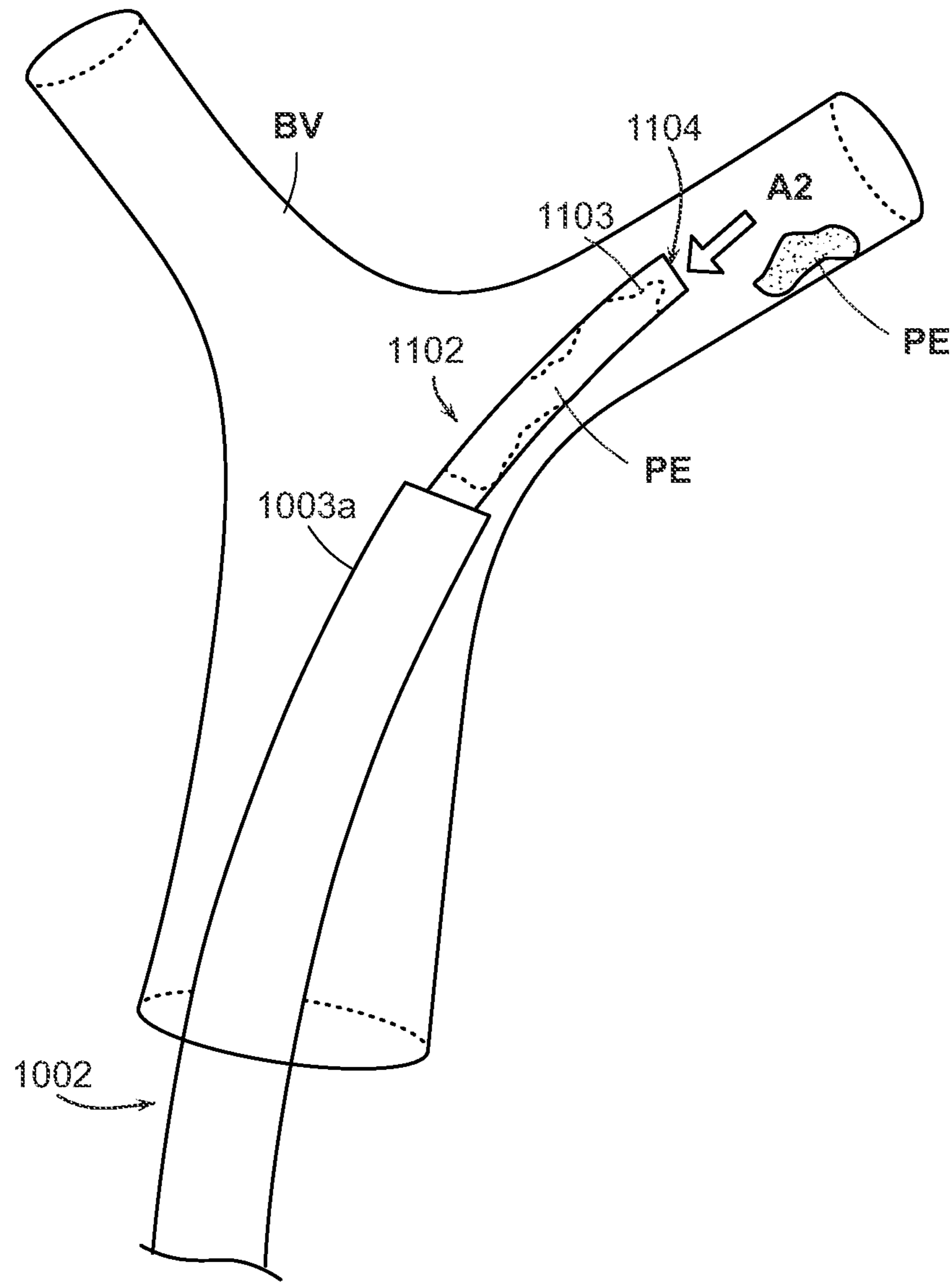


FIG. 13B

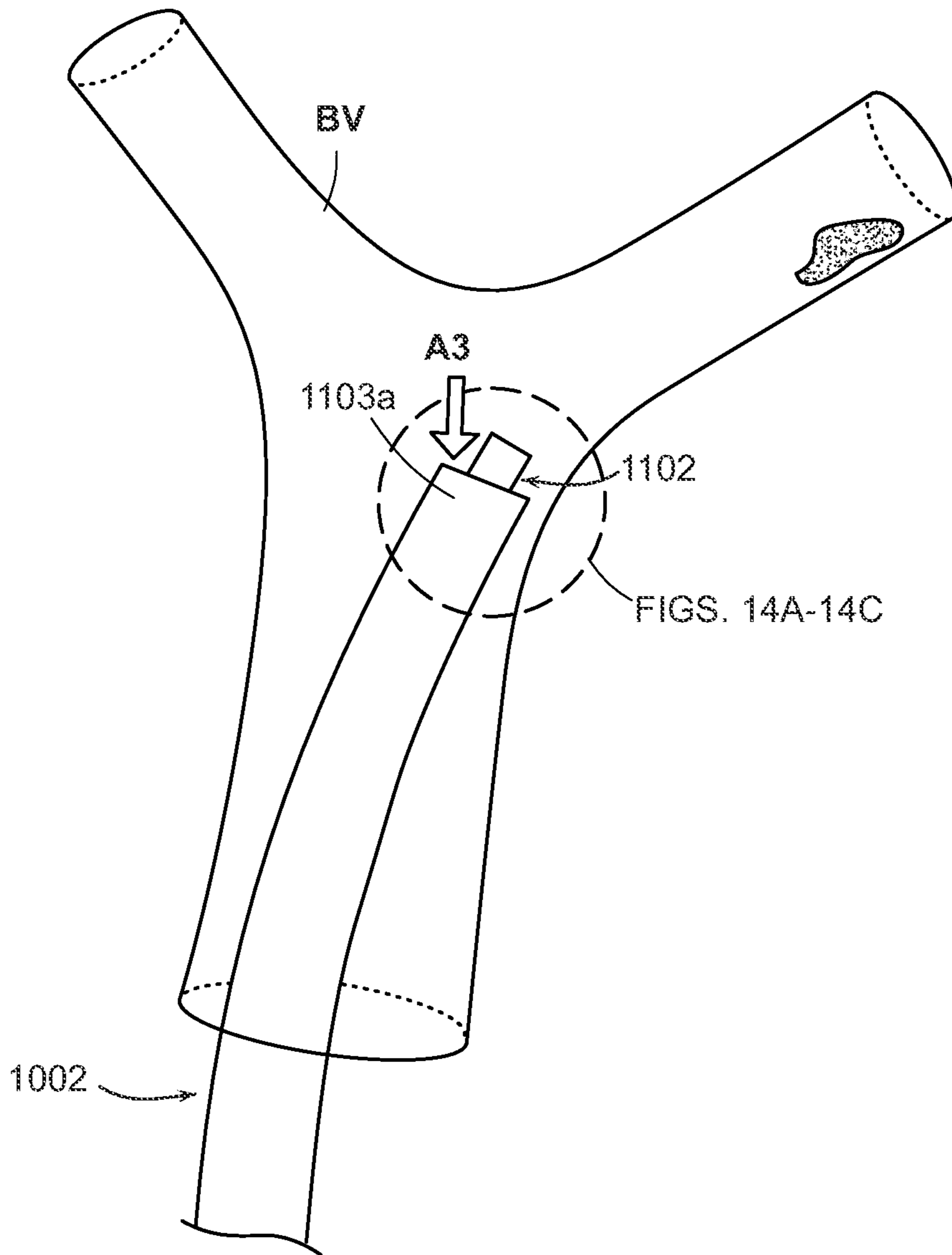


FIG. 13C

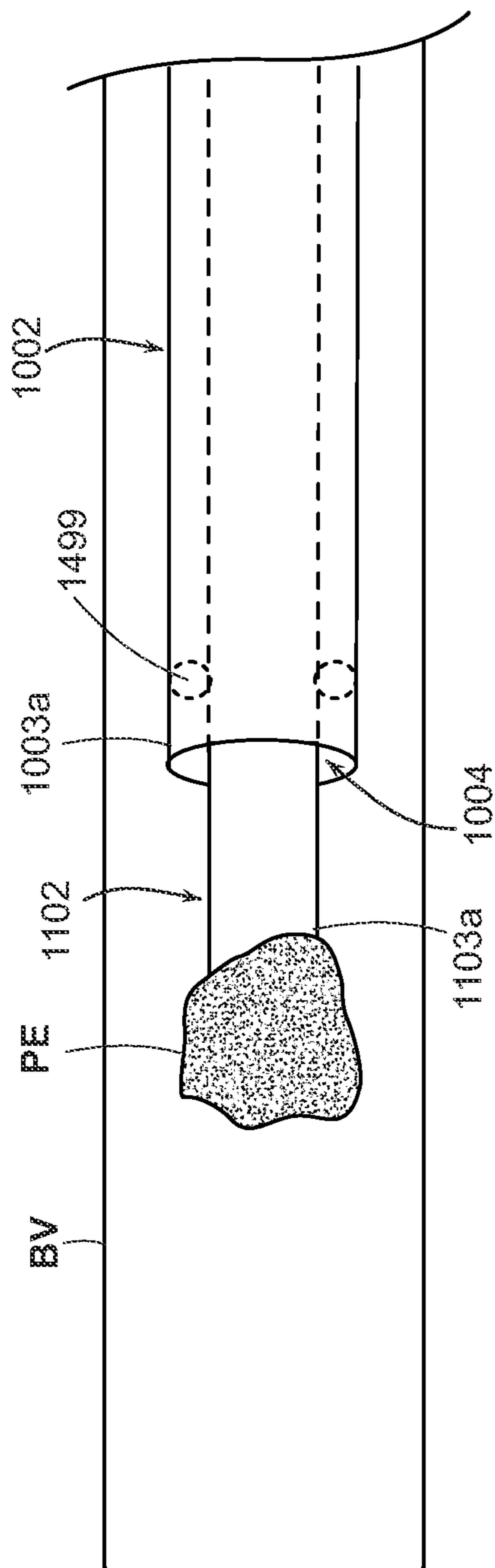


FIG. 14A

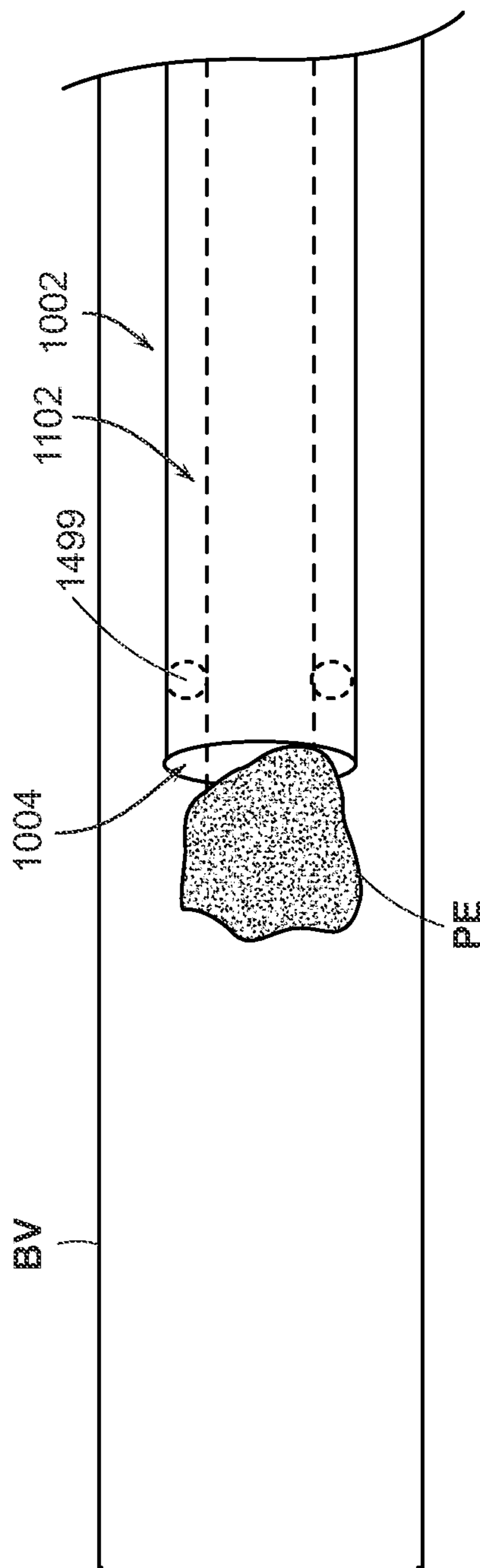


FIG. 14B

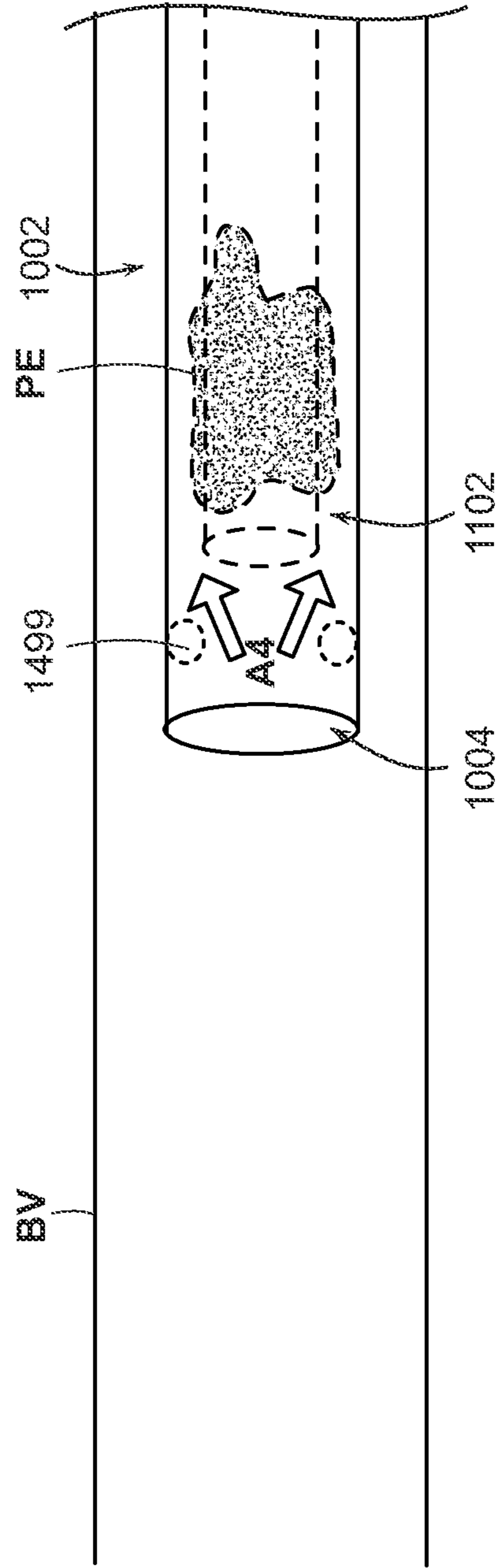


FIG. 14C

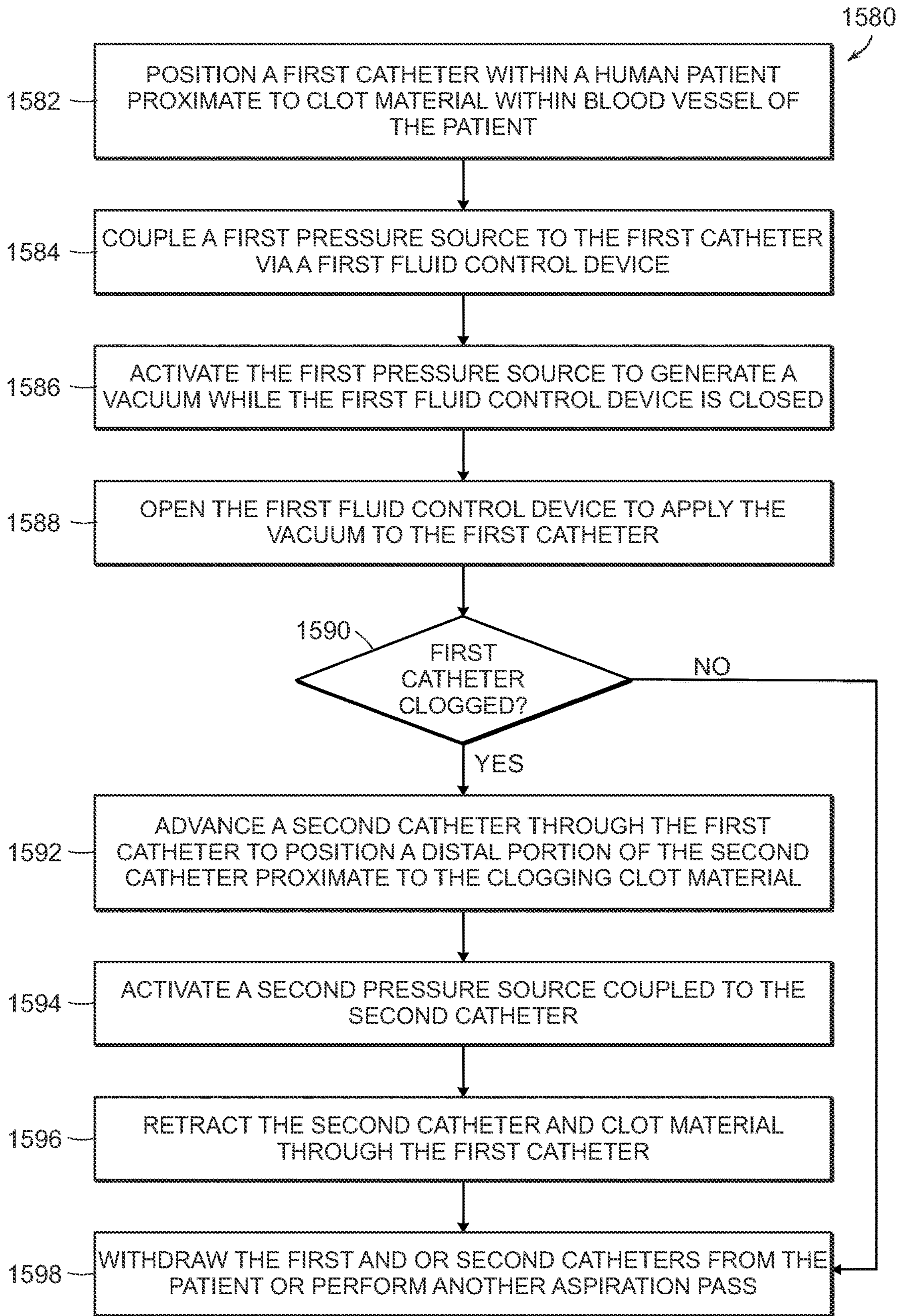
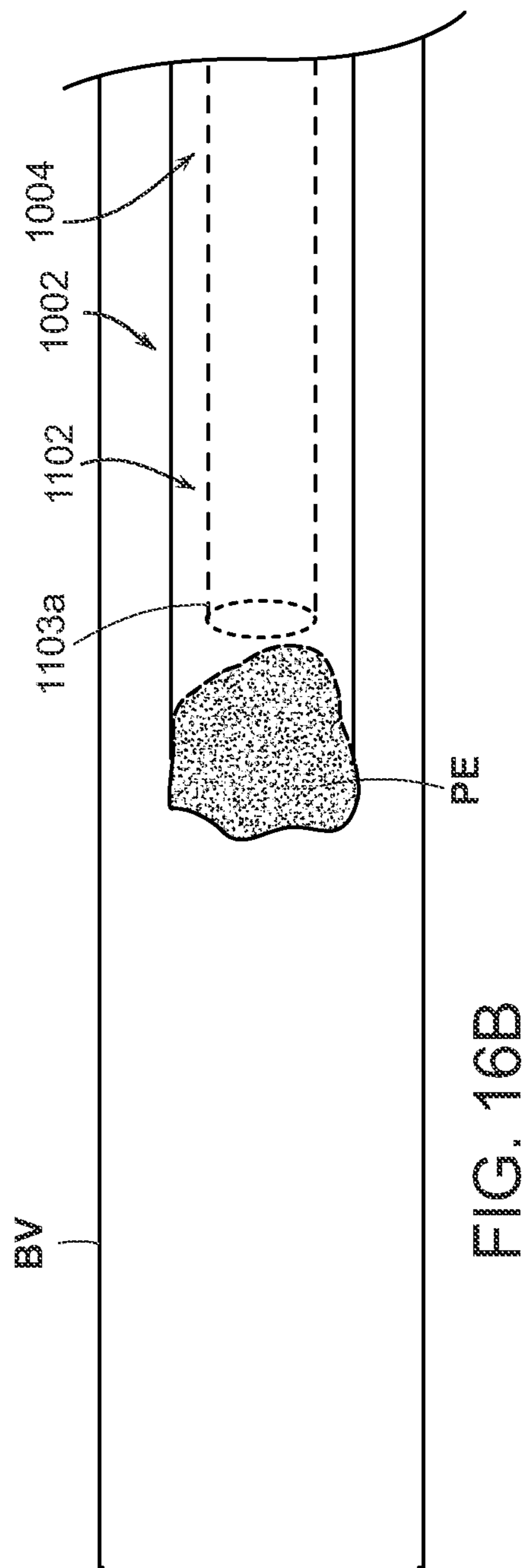
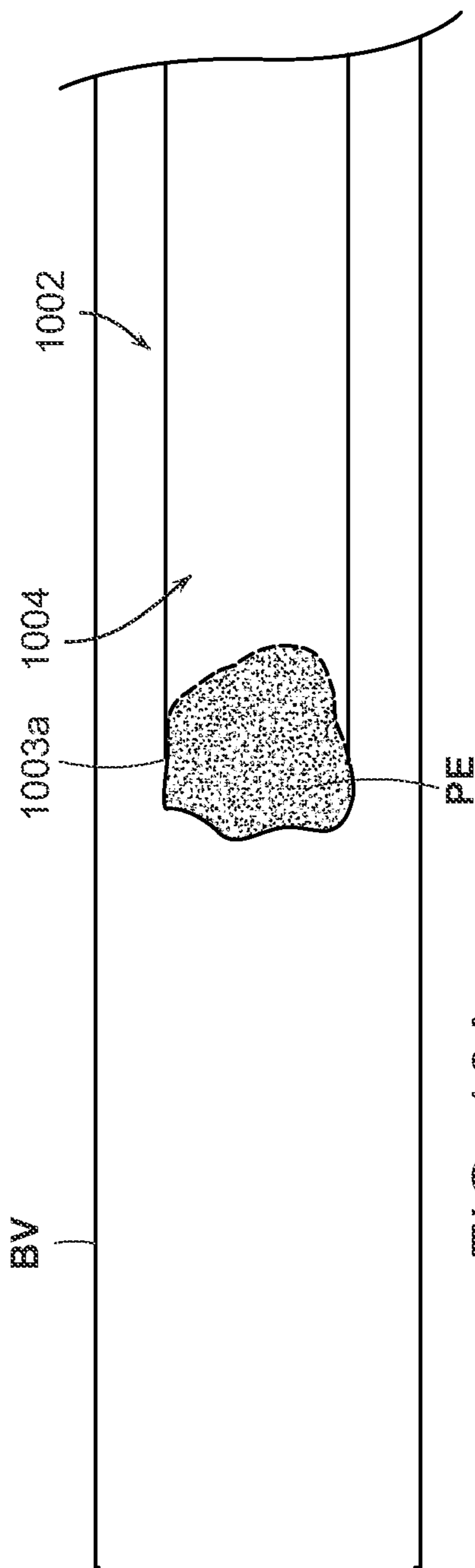


FIG. 15



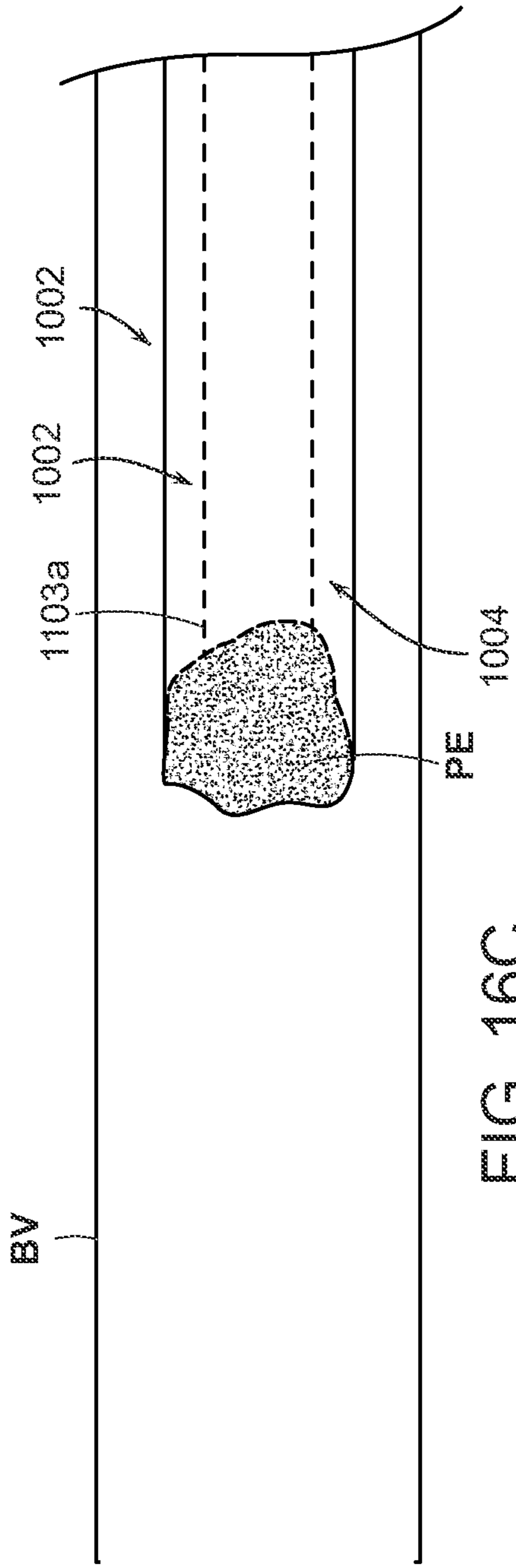


FIG. 16C

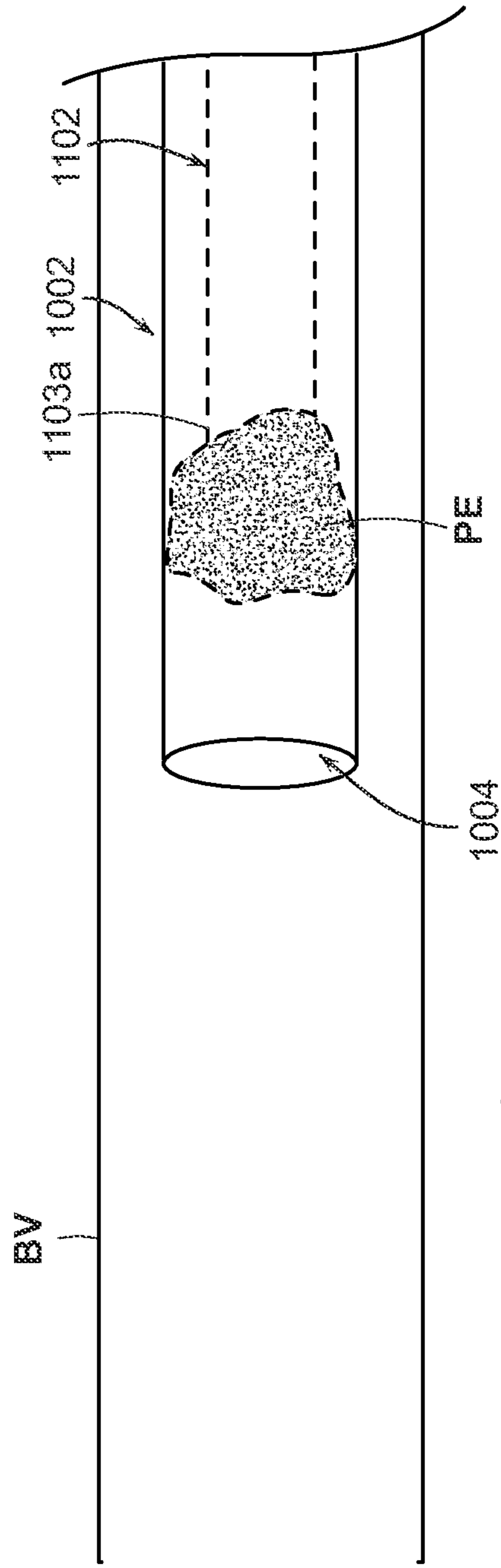


FIG. 16D

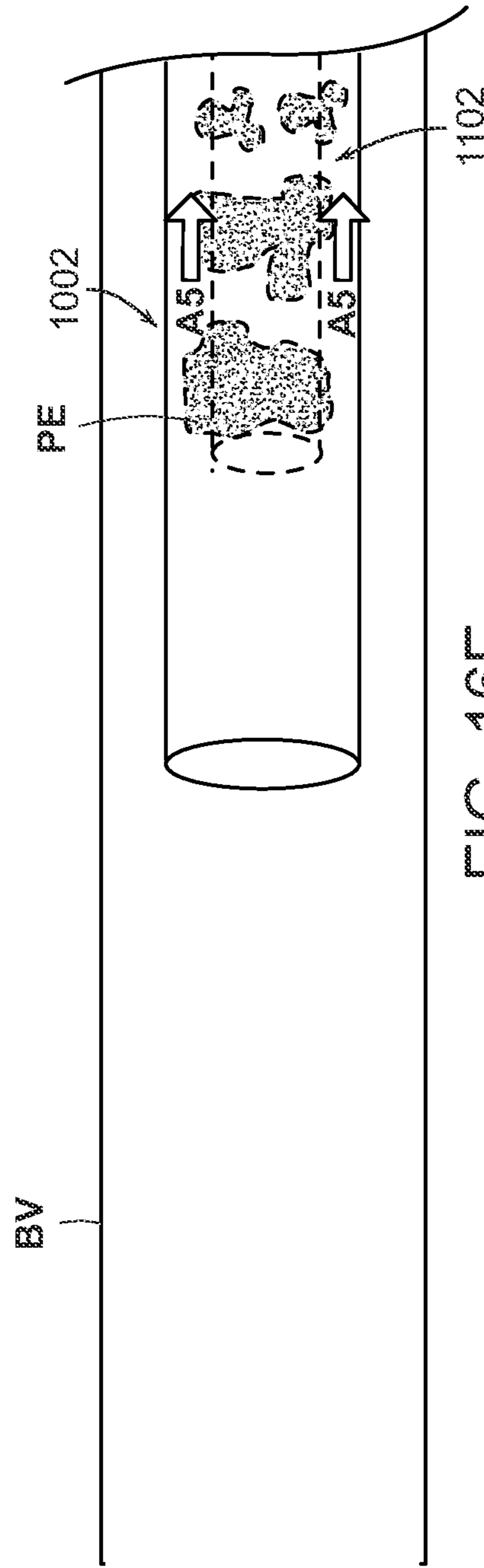
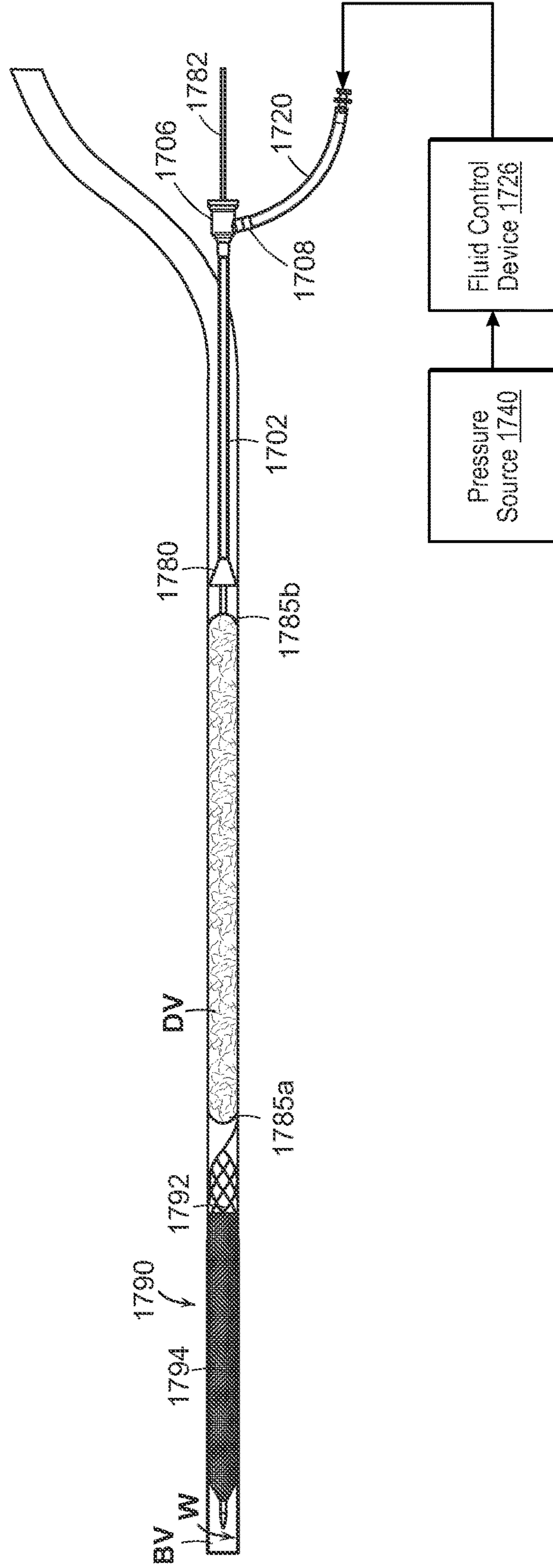


FIG. 16E

FIG. 17

1700 ↘



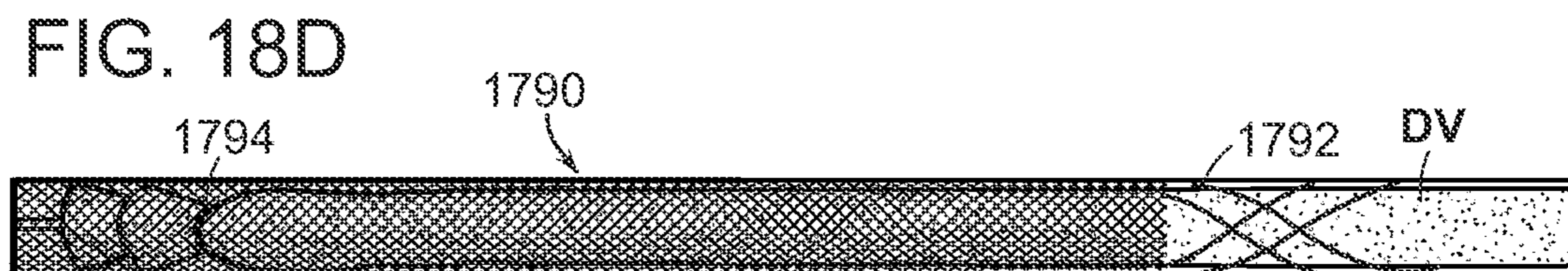
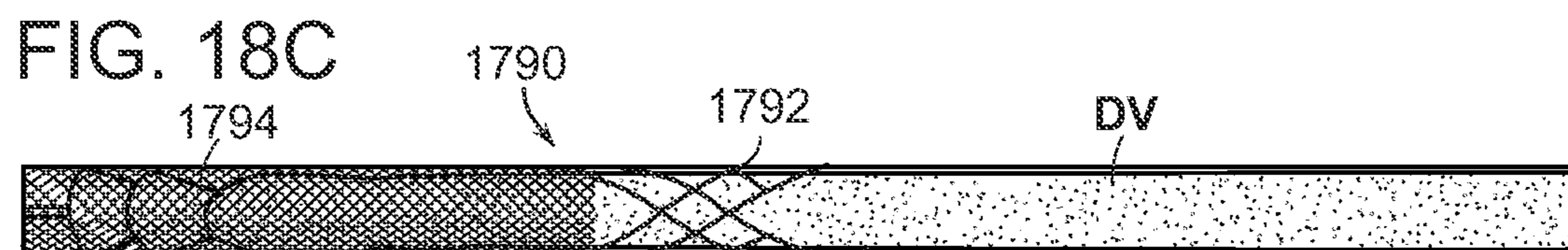
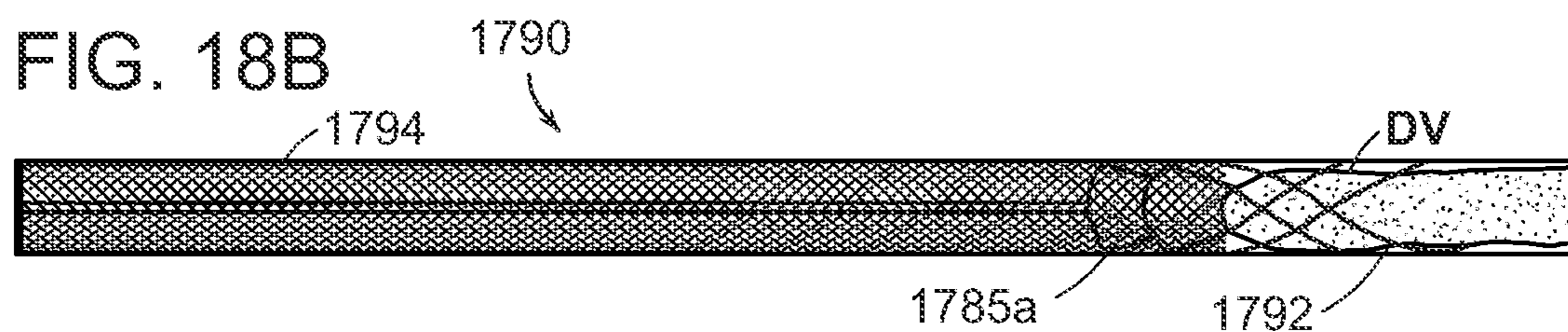
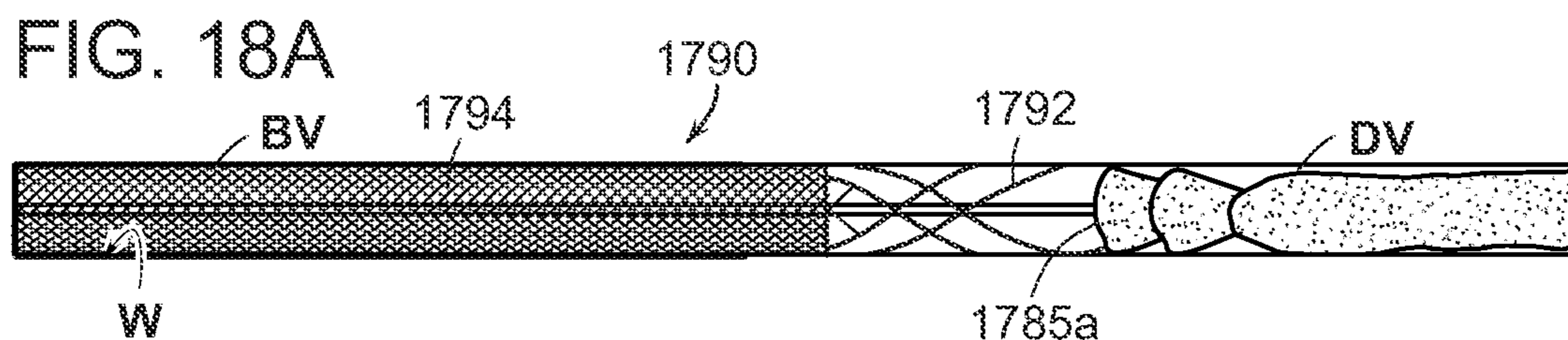


FIG. 18E

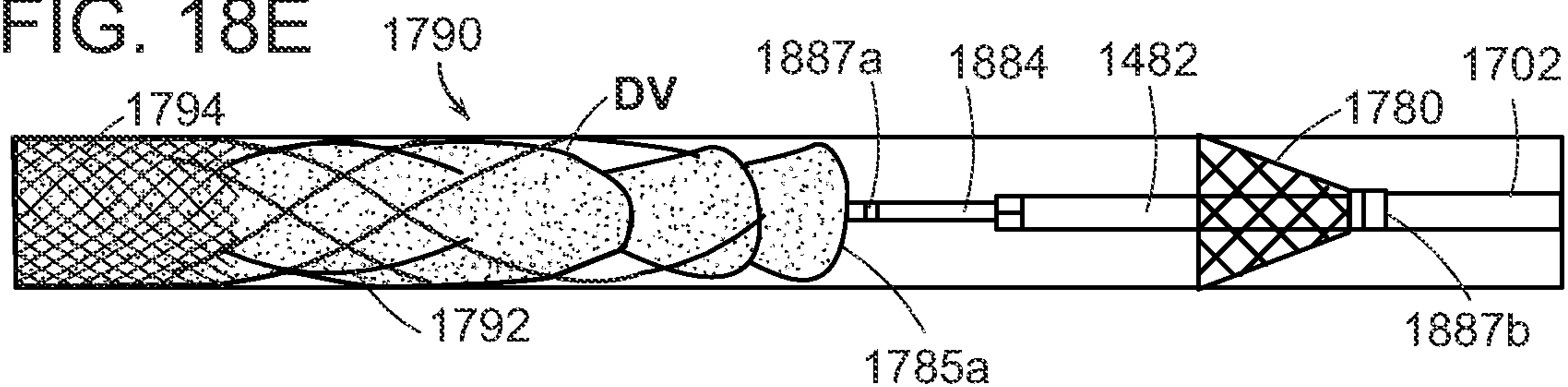


FIG. 18F

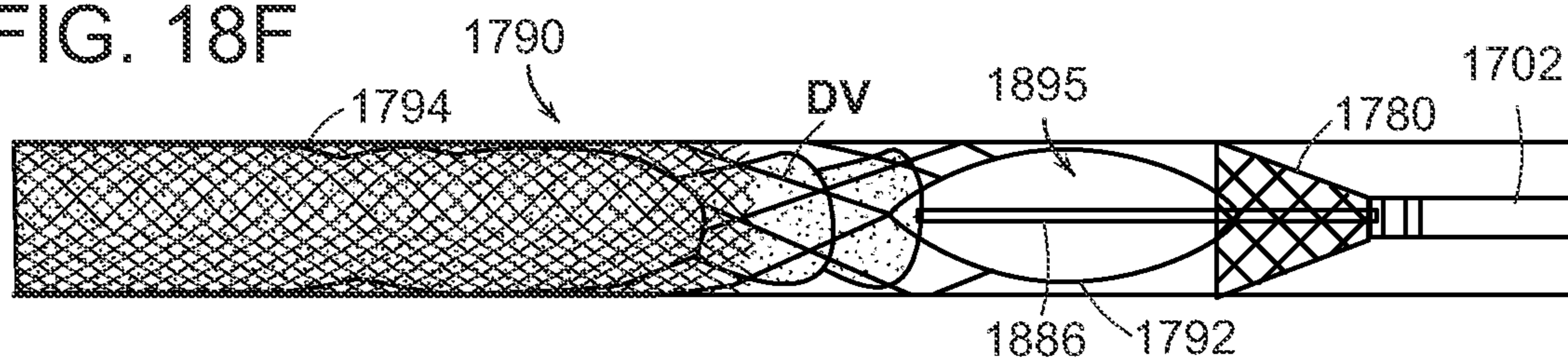


FIG. 18G

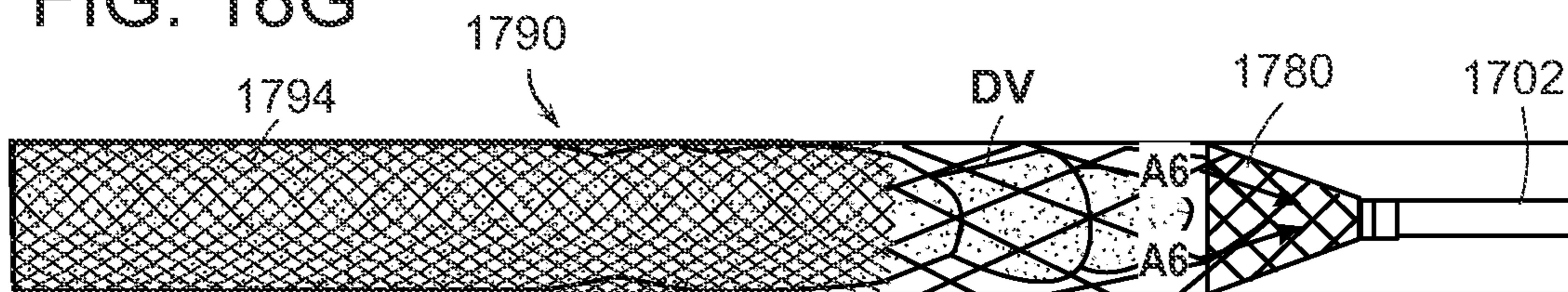
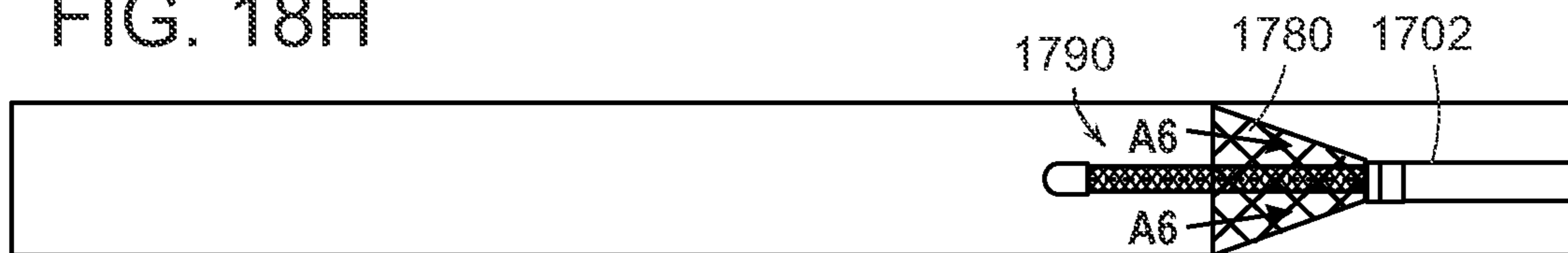


FIG. 18H



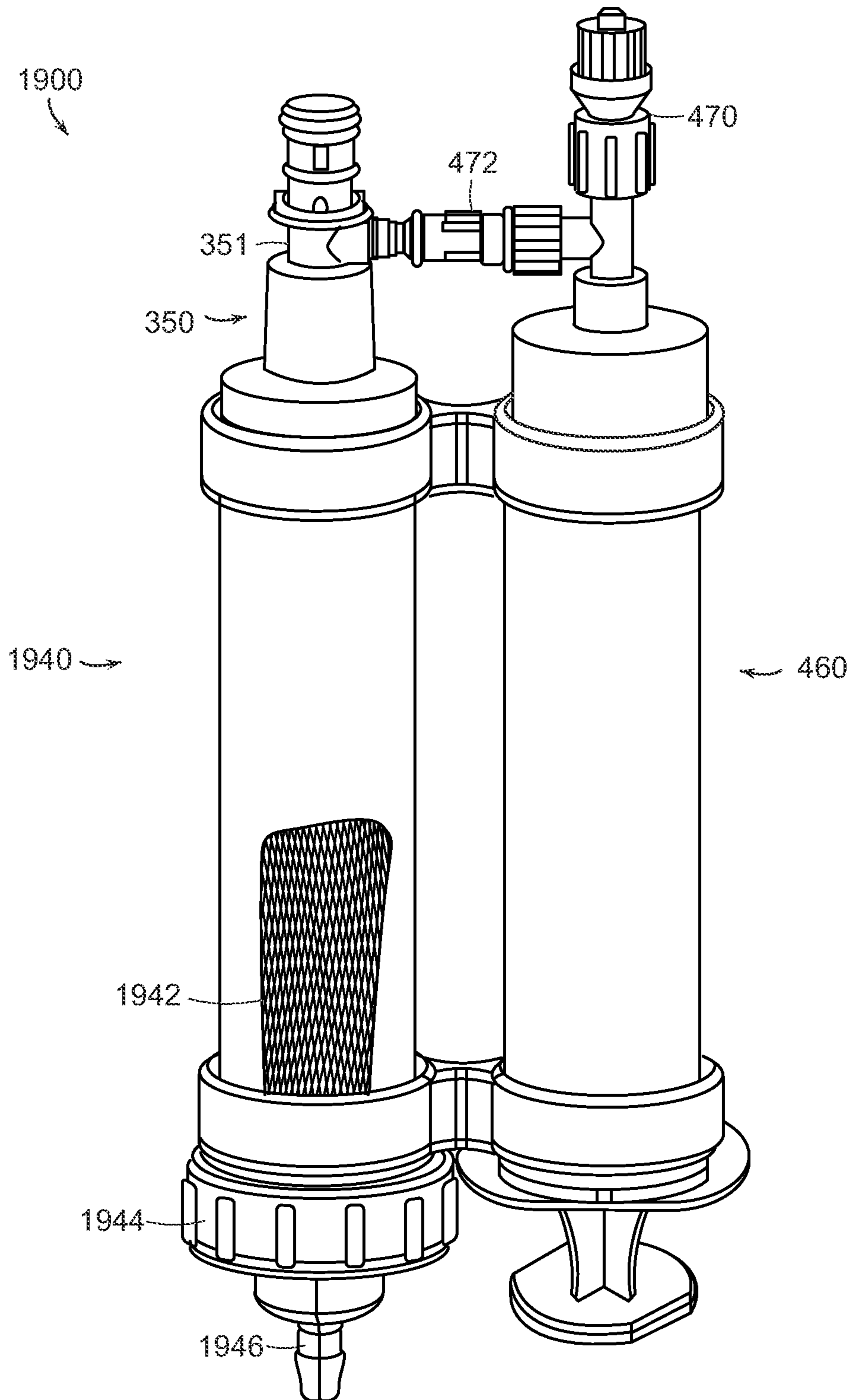


FIG. 19

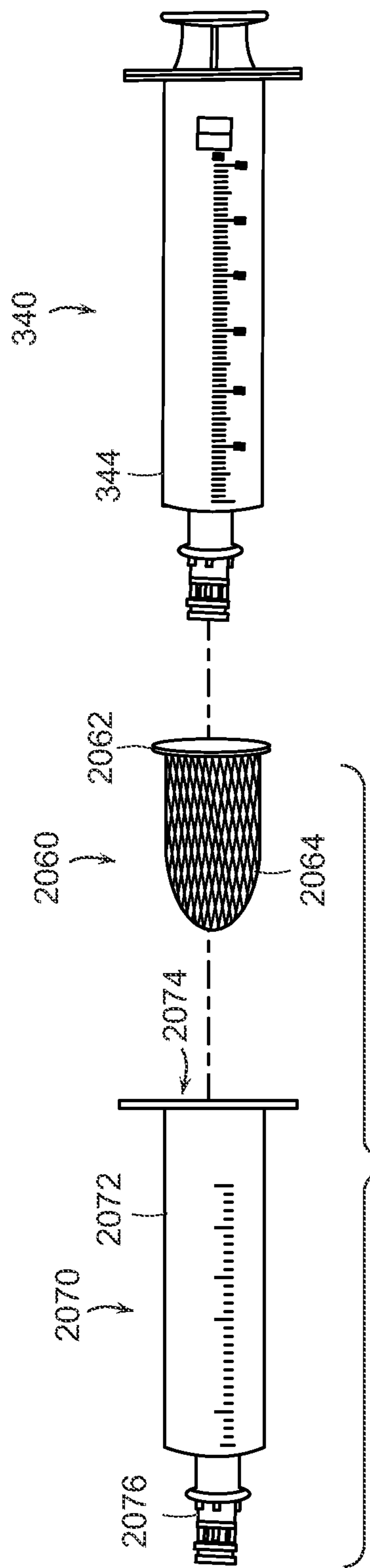


FIG. 20A

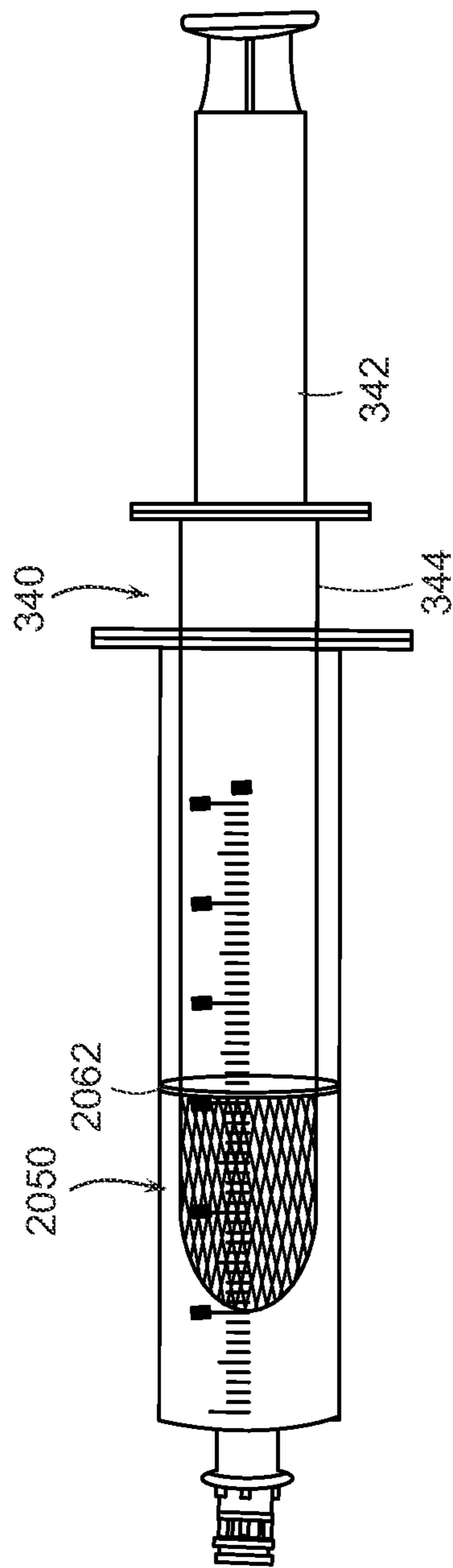


FIG. 20B

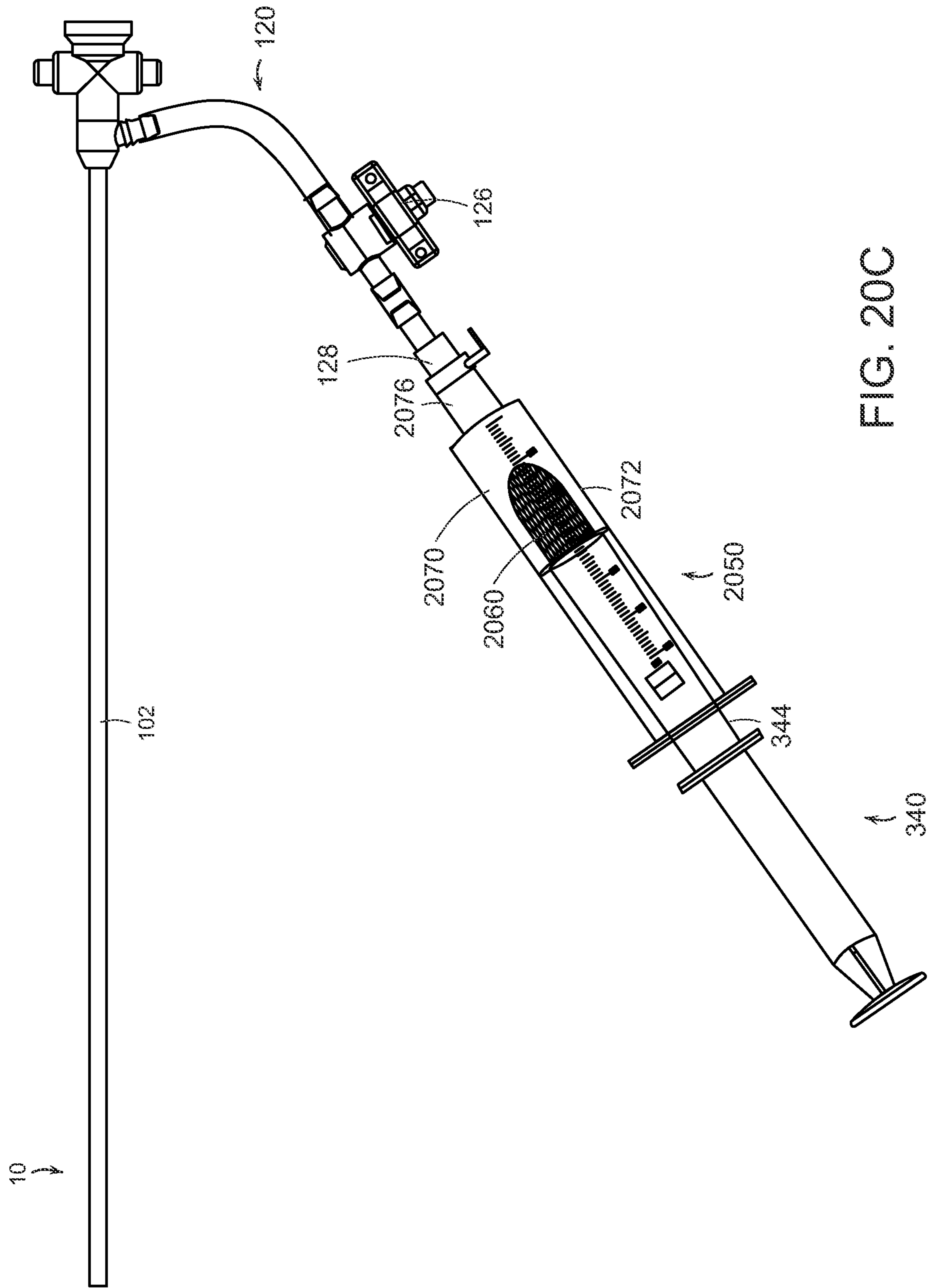


FIG. 20C

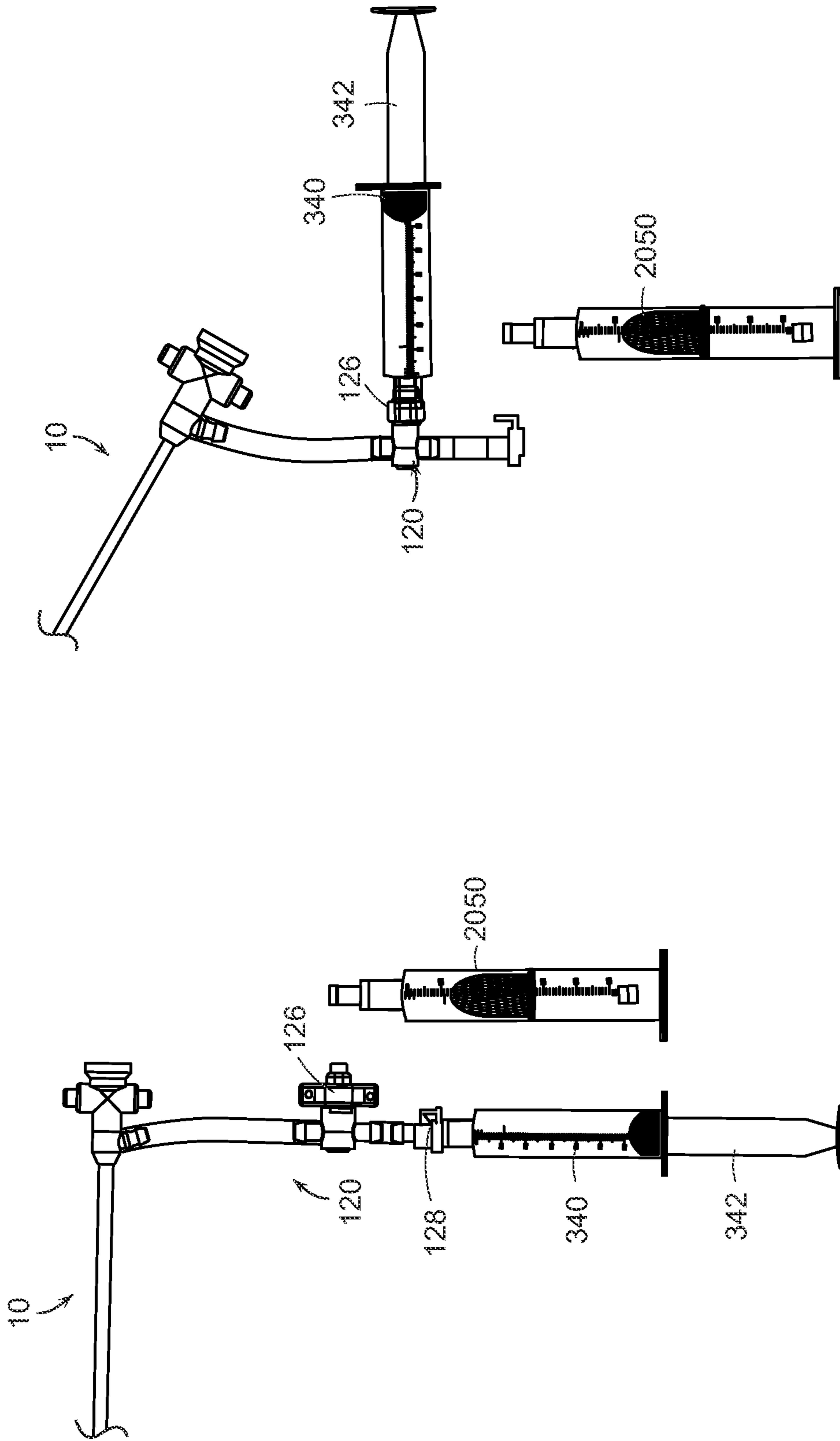


FIG. 20E

FIG. 20D

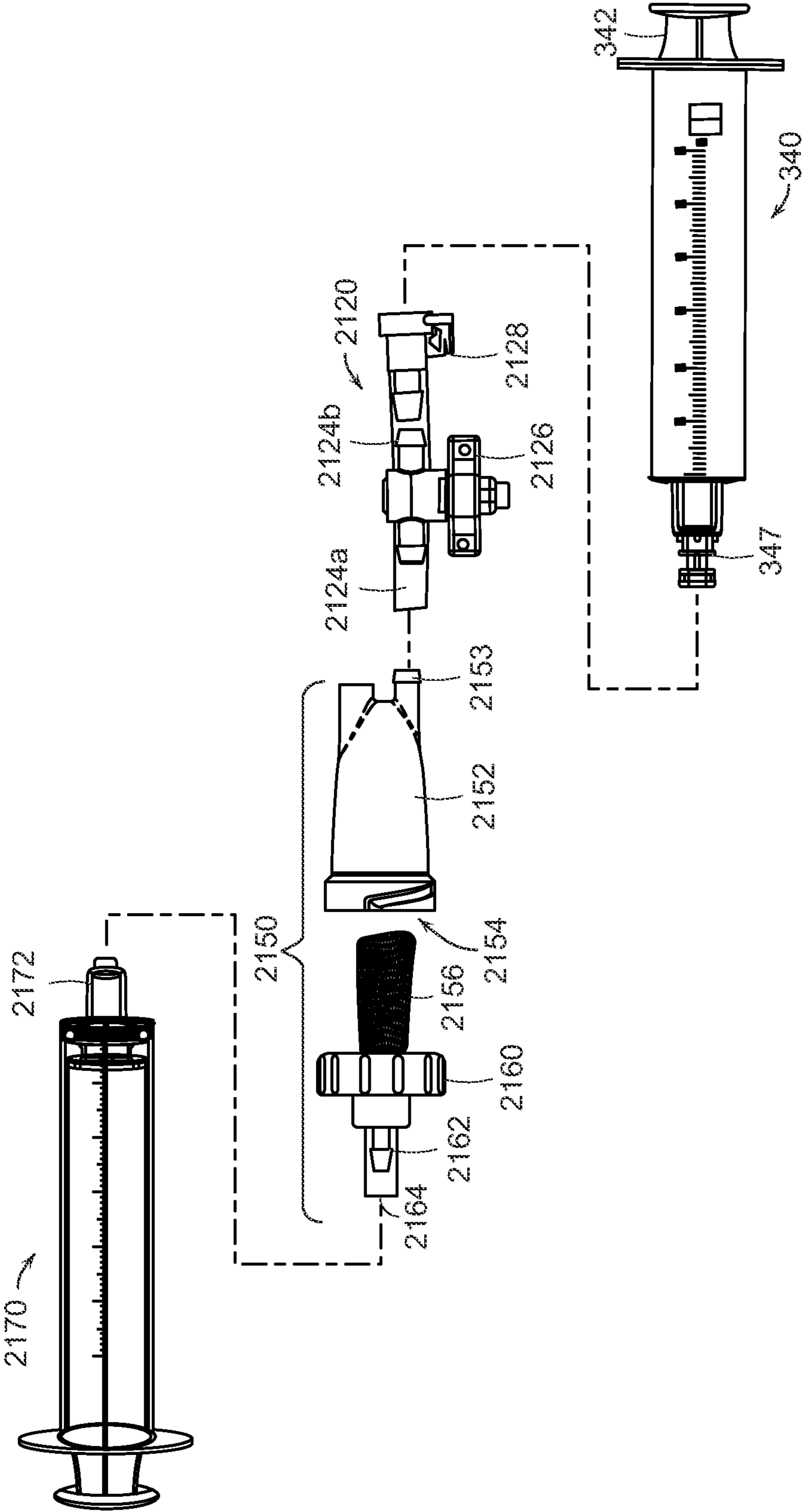


FIG. 21A

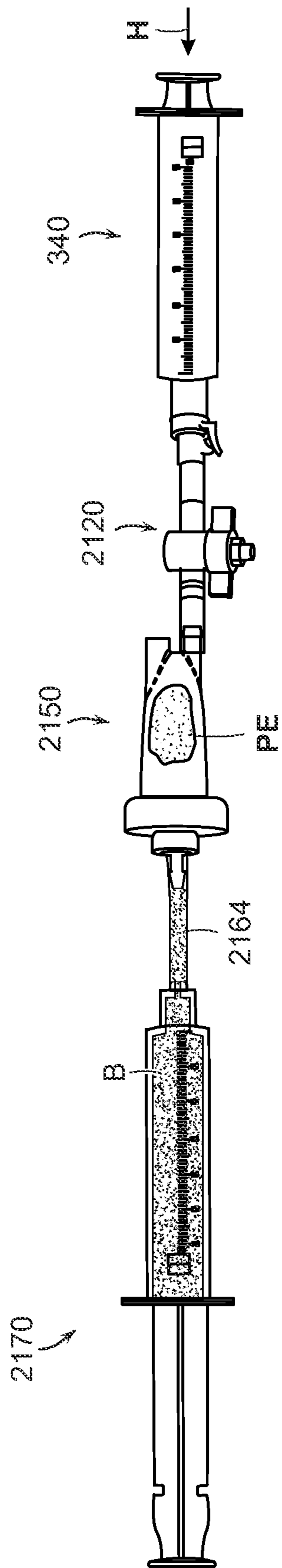


FIG. 21B

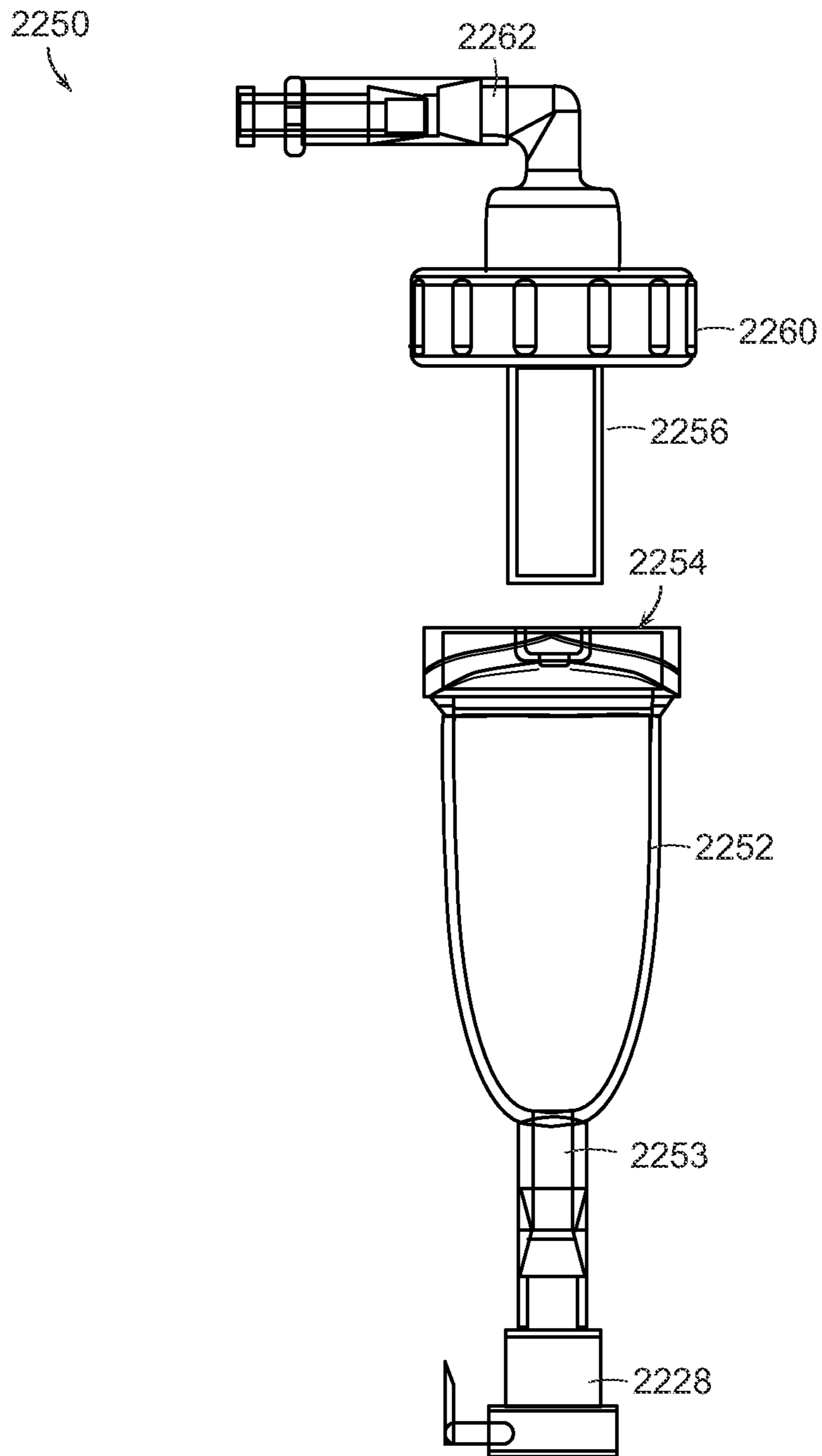


FIG. 22

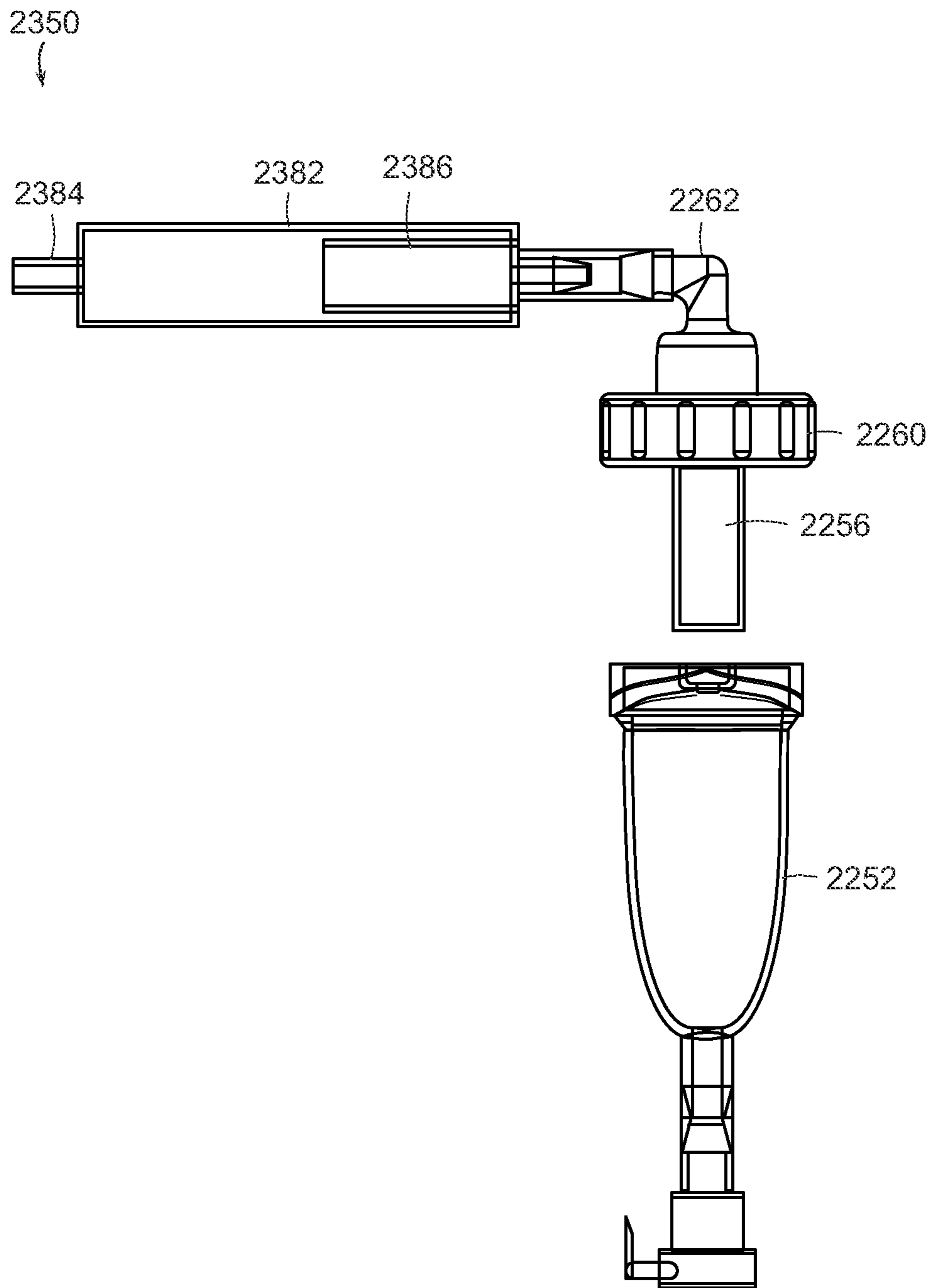


FIG. 23

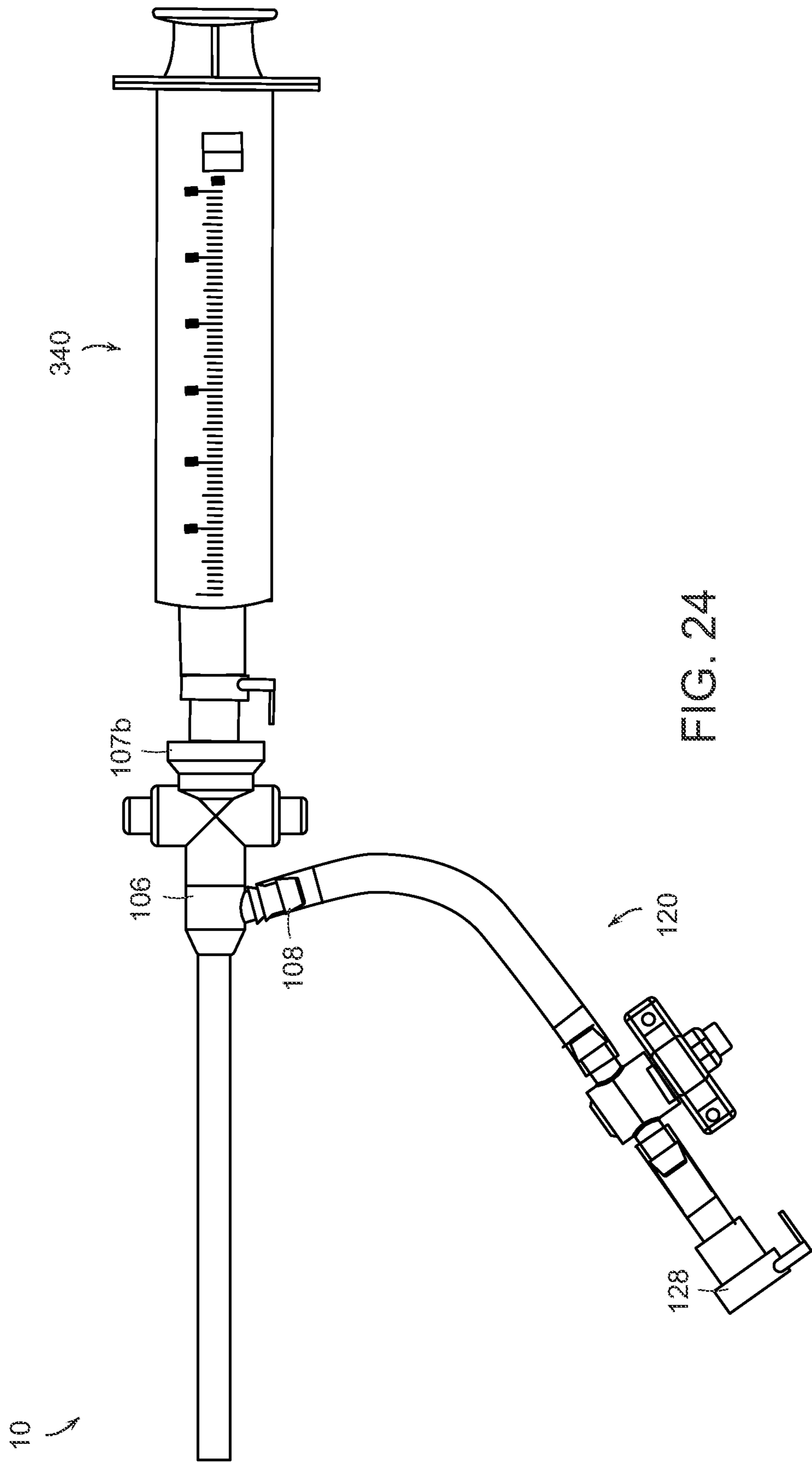


FIG. 24

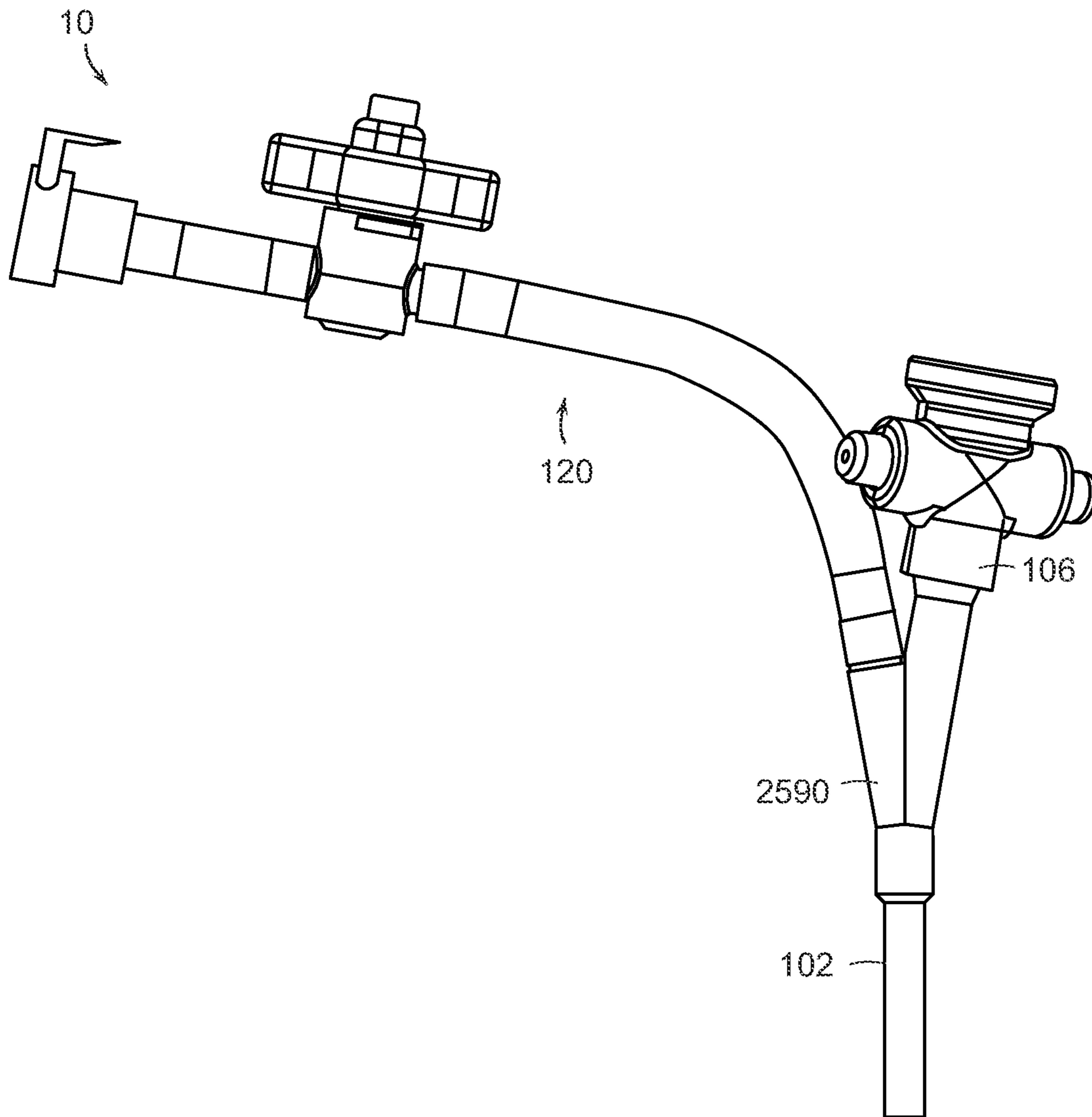


FIG. 25

SYSTEM FOR TREATING EMBOLISM AND ASSOCIATED DEVICES AND METHODS

CROSS-REFERENCES TO RELATED APPLICATIONS

This application is a continuation of U.S. patent application Ser. No. 18/167,757, filed Feb. 10, 2023, which is a continuation of U.S. patent application Ser. No. 17/976,711, filed Oct. 28, 2022, which is a continuation of U.S. patent application Ser. No. 17/865,315, filed Jul. 14, 2022, which is a continuation of U.S. patent application Ser. No. 16/536,185, filed Aug. 8, 2019, and issued as U.S. Pat. No. 11,559,382, which claims the benefit of U.S. Provisional Patent Application No. 62/718,269, filed on Aug. 13, 2018, and U.S. Provisional Patent Application No. 62/718,248, filed on Aug. 13, 2018, each of which is herein incorporated by reference in its entirety.

TECHNICAL FIELD

The present technology relates generally to systems, methods, and devices for the intravascular treatment of emboli and/or thrombi within a blood vessel of a human patient. In particular, some embodiments of the present technology relate to systems for releasing stored vacuum pressure to aspirate clot material from a blood vessel.

BACKGROUND

Thromboembolic events are characterized by an occlusion of a blood vessel. Thromboembolic disorders, such as stroke, pulmonary embolism, heart attack, peripheral thrombosis, atherosclerosis, and the like, affect many people. These disorders are a major cause of morbidity and mortality.

When an artery is occluded by a clot, tissue ischemia develops. The ischemia will progress to tissue infarction if the occlusion persists. However, infarction does not develop or is greatly limited if the flow of blood is reestablished rapidly. Failure to reestablish blood flow can accordingly lead to the loss of limb, angina pectoris, myocardial infarction, stroke, or even death.

In the venous circulation, occlusive material can also cause serious harm. Blood clots can develop in the large veins of the legs and pelvis, a common condition known as deep venous thrombosis (DVT). DVT commonly occurs where there is a propensity for stagnated blood (e.g., long distance air travel, immobility, etc.) and clotting (e.g., cancer, recent surgery, such as orthopedic surgery, etc.). DVT can obstruct drainage of venous blood from the legs leading to swelling, ulcers, pain and infection. DVT can also create a reservoir in which blood clots can collect and then travel to other parts of the body including the heart, lungs, brain (stroke), abdominal organs, and/or extremities.

In the pulmonary circulation, the undesirable material can cause harm by obstructing pulmonary arteries—a condition known as pulmonary embolism. If the obstruction is upstream, in the main or large branch pulmonary arteries, it can severely compromise total blood flow within the lungs, and therefore the entire body. This can result in low blood pressure and shock. If the obstruction is downstream, in large to medium pulmonary artery branches, it can prevent a significant portion of the lung from participating in the exchange of gases to the blood resulting in low blood oxygen and buildup of blood carbon dioxide.

There are many existing techniques to reestablish blood flow through an occluded vessel. Embolectomies, for example, are a surgical technique involving incising a blood vessel and placing a balloon-tipped device (such as the Fogarty catheter) at the location of the occlusion. The balloon is then inflated at a point beyond the clot and used to withdraw the obstructing material back to the point of incision. The obstructing material is then removed by the surgeon. Although such surgical techniques have been useful, exposing a patient to surgery may be traumatic and best avoided when possible. Additionally, the use of a Fogarty catheter may be problematic due to the possible risk of damaging the interior lining of the vessel as the catheter is being withdrawn.

Percutaneous methods are also utilized for reestablishing blood flow. A common percutaneous technique is referred to as balloon angioplasty where a balloon-tipped catheter is introduced to a blood vessel (e.g., typically through an introducing catheter). The balloon-tipped catheter is then advanced to the point of the occlusion and inflated to dilate the stenosis. Balloon angioplasty is appropriate for treating vessel stenosis, but it is generally not effective for treating acute thromboembolisms as none of the occlusive material is removed and restenosis regularly occurs after dilation. Another percutaneous technique involves placing a catheter near the clot and infusing streptokinase, urokinase, or other thrombolytic agents to dissolve the clot. Unfortunately, thrombolysis typically takes hours to days to be successful. Additionally, thrombolytic agents can cause hemorrhage, and in many patients the thrombolytic agents cannot be used at all.

Various devices exist for performing a thrombectomy or removing other foreign material. However, such devices have been found to have structures which are either highly complex, cause trauma to the treatment vessel, or lack the ability to be appropriately fixed against the vessel. Furthermore, many of the devices have highly complex structures that lead to manufacturing and quality control difficulties as well as delivery issues when passing through tortuous or small diameter catheters. Less complex devices may allow the user to pull through the clot, particularly with inexperienced users, and such devices may not completely capture and/or collect all of the clot material.

Thus, there exists a need for improved systems and methods for embolic extraction.

BRIEF DESCRIPTION OF THE DRAWINGS

Many aspects of the present technology can be better understood with reference to the following drawings. The components in the drawings are not necessarily to scale. Instead, emphasis is placed on illustrating clearly the principles of the present disclosure.

FIG. 1 is a partially schematic side view of a clot removal system configured in accordance with the present technology.

FIG. 2 is a side view of a locking syringe configured in accordance with the present technology.

FIG. 3A is a side view of a locking syringe configured in accordance with the present technology.

FIG. 3B is a side view of an adaptor for connecting the locking syringe of FIG. 3A to the clot removal system of FIG. 1 configured in accordance with the present technology.

FIG. 3C is a side view of the adaptor of FIG. 3B coupled to the locking syringe of FIG. 3A.

3

FIG. 3D is a side view of the locking syringe of FIG. 3A coupled to the clot removal system of FIG. 1 via the adaptor of FIG. 3B.

FIG. 4A is a perspective side view of another pressure source configured in accordance with the present technology, and FIGS. 4B and 4C are enlarged schematic side views of the pressure source of FIG. 4A during operation.

FIG. 5 is a cross-sectional side view of an automatic release syringe configured in accordance with the present technology.

FIG. 6 is a perspective top view of a syringe configured in accordance with the present technology.

FIG. 7 is a side view of an over-wire locking syringe configured in accordance with the present technology.

FIG. 8 is a flow diagram of a process or method for operating a clot removal system in accordance with the present technology.

FIGS. 9A-9C are side views of a proximal portion of the clot removal system of FIG. 1 during a clot removal procedure using the locking syringe of FIG. 3 in accordance with the present technology.

FIGS. 10A and 10B are schematic illustrations of a distal portion of the clot removal system of FIG. 1 during a clot removal procedure in accordance with the present technology.

FIG. 11 is a partially schematic side view of another clot removal system configured in accordance with the present technology.

FIG. 12 is a flow diagram of another process or method for operating a clot removal system in accordance with the present technology.

FIGS. 13A-14C are schematic illustrations of a distal portion of the clot removal system of FIG. 11 during a clot removal procedure in accordance with the present technology.

FIG. 15 is a flow diagram of another process or method for operating a clot removal system in accordance with the present technology.

FIGS. 16A-16E are schematic illustrations of a distal portion of the clot removal system of FIG. 11 during a clot removal procedure in accordance with the present technology.

FIG. 17 is a partially schematic side view of another clot removal system configured in accordance with the present technology.

FIGS. 18A-18H are side views of a distal portion of the clot removal system shown of FIG. 17 during a clot removal procedure in accordance with the present technology.

FIG. 19 is a perspective side view of a pressure source for filtering blood from aspirated clot material during a clot removal procedure configured in accordance with the present technology.

FIG. 20A is a partially-exploded side view of a filter device and pressure source configured in accordance with the present technology.

FIG. 20B is a perspective side view of the syringe of FIG. 20A coupled to the filter device of the FIG. 20A.

FIG. 20C is a side view of the filter device and syringe of FIG. 20B coupled to the clot removal system of FIG. 1.

FIGS. 20D and 20E are side views of the syringe of FIG. 20A coupled to the clot removal system of FIG. 1 for reintroducing blood to a patient.

FIG. 21A is a partially-exploded side view of a filter device, a pressure source, and a reinfusion syringe configured in accordance with the present technology.

4

FIG. 21B is a perspective side view of the filter device of FIG. 21A coupled to the pressure source and the reinfusion syringe of FIG. 21A.

FIG. 22 is a partially-exploded side view of a filter device configured in accordance with the present technology.

FIG. 23 is a partially-exploded side view of a filter device configured in accordance with the present technology.

FIG. 24 is an enlarged isometric view of the clot removal system of FIG. 1 configured in accordance with the present technology.

FIG. 25 is an enlarged isometric view of the clot removal system of FIG. 1 configured in accordance with the present technology.

DETAILED DESCRIPTION

The present technology is generally directed to methods and systems for removing clot material from a blood vessel of a human patient. In some embodiments, a catheter can be intravascularly positioned within a blood vessel such that a distal portion (e.g., a distal opening) of the catheter is positioned proximate to clot material within the blood vessel. The catheter can be fluidly coupled to a pressure source via a valve or other fluid control device positioned outside of the patient. With the valve closed, the pressure source can be activated to charge a vacuum chamber of the pressure source with a vacuum. The valve can then be opened to apply the vacuum to the catheter to thereby aspirate at least a portion of the clot material from the blood vessel into the catheter. In some embodiments, an interventional device can be delivered through the catheter and used to engage the clot material before and/or after the vacuum is applied to the catheter.

In one aspect of the present technology, the pressure source is configured to generate a vacuum and store the vacuum before the pressure source is fluidly connected to the catheter. Therefore, opening the fluid control device can instantaneously or nearly instantaneously apply the stored vacuum pressure to the catheter, thereby generating suction throughout the catheter. In particular, the suction is applied at the distal portion of the catheter proximate to the clot material. Pre-charging or storing the vacuum before applying the vacuum to the catheter can generate greater suction forces (and corresponding fluid flow velocities) at and/or near the distal portion of the catheter compared to, for example, simply activating the pressure source while it is fluidly connected to the catheter. The greater suction forces generated by application of the stored vacuum can be used to aspirate or otherwise remove clot material from within a blood vessel of a human patient.

Although many of the embodiments are described below with respect to devices, systems, and methods for treating a pulmonary embolism, other applications and other embodiments in addition to those described herein are within the scope of the technology (e.g., intravascular procedures other than the treatment of emboli, intravascular procedures for treating cerebral embolism, intravascular procedures for treating deep vein thrombosis (DVT), etc.). Additionally, several other embodiments of the technology can have different configurations, states, components, or procedures than those described herein. Moreover, it will be appreciated that specific elements, substructures, advantages, uses, and/or other features of the embodiments described with reference to FIGS. 1-25 can be suitably interchanged, substituted or otherwise configured with one another in accordance with additional embodiments of the present technology. Furthermore, suitable elements of the embodiments described with

reference to FIGS. 1-25 can be used as standalone and/or self-contained devices. A person of ordinary skill in the art, therefore, will accordingly understand that the technology can have other embodiments with additional elements, or the technology can have other embodiments without several of the features shown and described below with reference to FIGS. 1-25.

With regard to the terms “distal” and “proximal” within this description, unless otherwise specified, the terms can reference a relative position of the portions of a catheter subsystem with reference to an operator and/or a location in the vasculature. Also, as used herein, the designations “rearward,” “forward,” “upward,” “downward,” etc. are not meant to limit the referenced component to use in a specific orientation. It will be appreciated that such designations refer to the orientation of the referenced component as illustrated in the Figures; the systems of the present technology can be used in any orientation suitable to the user.

The headings provided herein are for convenience only and should not be construed as limiting the subject matter disclosed.

I. Selected Embodiments of Clot Removal Systems

FIG. 1 is a partially schematic side view of a clot treatment or clot removal system comprising an aspiration assembly 10 (“assembly 10”) configured in accordance with an embodiment of the present technology. In the illustrated embodiment, the assembly 10 includes a catheter subsystem 100, a tubing subsystem 120, and a pressure source 140. The catheter subsystem 100 includes a catheter 102 (e.g., an aspiration catheter) comprising an elongated shaft defining a lumen 104 and having a distal portion 103a and a proximal portion 103b. The catheter subsystem 100 further includes a valve 106 that can be integral with or coupled to the proximal portion 103b of the catheter 102.

In the illustrated embodiment, the valve 106 includes a distal portion 107a, a proximal portion 107b, and a lumen 109 extending therethrough from the distal portion 107a to the proximal portion 107b. The valve 106 further includes a flow controller (obscured in FIG. 1) in the lumen 109. In some embodiments, the valve is a hemostasis valve that is configured to maintain hemostasis during a clot removal procedure by preventing fluid flow in the proximal direction through the valve 106 as various components such as delivery sheaths, pull members, guidewires, interventional devices, other aspiration catheters (e.g., as described in detail with reference to FIGS. 11-16E), etc., are inserted through the valve 106 to be delivered through the catheter 102 to a treatment site in a blood vessel. The valve 106 further includes a branch or side port 108 positioned distally of the flow controller in the lumen 109 and configured to fluidly couple the lumen 104 of the catheter 102 to the tubing subsystem 120. In the illustrated embodiment, the valve 106 includes buttons 101 that can be actuated (e.g., depressed) to open a conduit within the lumen 109. In some embodiments, the valve 106 can be a valve of the type disclosed in U.S. patent application Ser. No. 16/117,519, filed Aug. 30, 2018, and titled “HEMOSTASIS VALVES AND METHODS OF USE,” which is incorporated herein by reference in its entirety. In some embodiments, the proximal portion 107b of the valve 106 is further configured to be detachably coupled (e.g., via a snap-fit arrangement) to a retraction/aspiration device for aspirating the lumen 104 of the catheter 102 and/or for retracting an interventional device, catheter, delivery sheath, catheter, etc., positioned within the lumen 104. Specific details of such retraction/aspiration devices

and associated methods are disclosed in U.S. Pat. No. 9,526,864, filed Jun. 9, 2015, and titled “RETRACTION AND ASPIRATION DEVICE FOR TREATING EMBOLISM AND ASSOCIATED SYSTEMS AND METHODS,” which is incorporated herein by reference in its entirety.

The tubing subsystem 120 fluidly couples the catheter subsystem 100 to the pressure source 140. More specifically, the tubing subsystem 120 can include one or more tubing sections 124 (individually labeled as a first tubing section 124a and a second tubing section 124b), at least one fluid control device 126 (e.g., a valve), and at least one connector 128 for fluidly coupling the tubing subsystem 120 to the pressure source 140 and/or other suitable components. More specifically, in the illustrated embodiment, the fluid control device 126 is a stopcock that is fluidly coupled to (i) the side port 108 of the valve 106 via the first tubing section 124a and (ii) the connector 128 via the second tubing section 124b. In some embodiments, the fluid control device 126 can define a lumen having a diameter (or other cross-sectional dimension) that is greater than or equal to a diameter of the lumen 104 of the catheter 102, a diameter of the first tubing section 124a, and/or a diameter of the second tubing section 124b.

The fluid control device 126 is externally operable by a user to regulate the flow of fluid therethrough and, specifically, from the lumen 104 of the catheter 102 to the pressure source 140. In other embodiments, the fluid control device 126 can be a clamp that can be actuated (e.g., compressed or squeezed by the hand of a user) to partially or fully restrict fluid flow through the tubing section 124a and/or the tubing section 124b. In yet other embodiments, the fluid control device 126 can be omitted and its functionality incorporated into the pressure source 140 (e.g., as described in detail below with reference to FIG. 5). In some embodiments, the fluid control device 126 can include a quick-release mechanism (e.g., a spring-loaded apparatus) for rapidly opening, unclamping, etc., the fluid control device 126 to (e.g., instantaneously or nearly instantaneously) fluidly connect the pressure source 140 and the catheter 102. In some embodiments, the fluid control device 126 can be opened/closed automatically (e.g., by a motor, switch, etc.). When the pressure source 140 is pre-charged with a vacuum, as described in detail below, such a quick-release fluid control device 126 can reduce the time needed for pressure in the assembly 10 to equalize after opening of the fluid control device 126, and can thereby increase suction forces generated at the distal portion 103a of the catheter 102.

In some embodiments, the connector 128 is a quick-release connector (e.g., a quick disconnect fitting) that enables rapid coupling/decoupling of the catheter 102 and the fluid control device 126 to/from the pressure source 140. In other embodiments, the tubing subsystem 120 can have more or fewer tubing sections, connectors, and/or fluid control devices, and can have other suitable configurations. In some embodiments, one or more of the components can be permanently connected and/or integrally formed.

The pressure source 140 is configured to generate (e.g., form, create, charge, build-up, etc.) a vacuum (e.g., negative relative pressure) and store the vacuum for subsequent application to the catheter subsystem 100. Further details of suitable pressure sources are described in detail below with reference to FIGS. 2-7. During operation of the assembly 10, a user can first close the fluid control device 126 before activating the pressure source 140 to build up vacuum pressure within the pressure source 140 (e.g., a vacuum chamber of the pressure source 140). In some embodiments, the user can control or select the volume of the generated

vacuum. In this manner, a vacuum is charged within the pressure source 140 before the pressure source 140 is fluidly connected to the catheter subsystem 100. To aspirate the lumen 104 of the catheter 102, the user can open the fluid control device 126 to fluidly connect the pressure source 140 to the catheter subsystem 100 and thereby apply or release the vacuum stored in the pressure source 140 to the lumen 104 of the catheter 102. Opening of the fluid control device 126 instantaneously or nearly instantaneously applies the stored vacuum pressure to the tubing subsystem 120 and the catheter 102, thereby generating suction throughout the catheter 102. In particular, the suction is applied at the distal portion 103a of the catheter 102. In one aspect of the present technology, pre-charging or storing the vacuum before applying the vacuum to the lumen 104 of the catheter 102 is expected to generate greater suction forces (and corresponding fluid flow velocities) at and/or near the distal portion 103a of the catheter 102 compared to simply activating the pressure source 140 while it is fluidly connected to the catheter 102. As described in detail below, the suction forces generated by application of the stored vacuum can be used to aspirate or otherwise remove clot material from within a blood vessel of a human patient.

II. Selected Embodiments of Pressure Sources for Use with Clot Removal Systems

As described in detail above with reference to FIG. 1, the assembly 10 of the present technology includes a pressure source (e.g., a vacuum source, negative pressure source, etc.) configured to charge a vacuum that can be applied to the catheter subsystem 100 to generate suction forces for aspirating clot material from within a blood vessel. In general, the pressure source can be any suitable source or combination of sources for generating and/or storing negative pressure. In some embodiments, the pressure source can be a pump (e.g., an electric pump coupled to a vacuum chamber) while, in other embodiments, the pressure source can include one or more syringes that can be actuated or otherwise activated by a user of the assembly 10 to generate and store a vacuum therein.

FIG. 2 is a side view of a pressure source 240 comprising a vacuum-pressure locking syringe ("syringe 240") configured in accordance with the present technology. In some embodiments, the syringe 240 can be of the kind sold under the trademark "VacLok" by Merit Medical System, Inc. In the illustrated embodiment, the syringe 240 includes a plunger 242 slidably and rotatably positioned within a chamber or barrel 244. The barrel 244 is shown as transparent in FIG. 2 for the sake of clarity. The plunger 242 includes a seal 243 and a plurality of index members 246 defining slots 248 between adjacent pairs thereof. A tab member 245 projects inwardly from the interior surface of the barrel 244 and is configured to be removably positioned in the slots 248 for locking the plunger 242 in position relative to the barrel 244. In some embodiments, the barrel 244 can be made of a transparent material that permits a user to visualize material (e.g., clot material) within the barrel 244 and to visualize the relative position between the slots 248 and tab member 245 for locking the syringe 240.

Referring to both FIGS. 1 and 2 together, the syringe 240 further includes a tip 247 for coupling the syringe 240 to the tubing subsystem 120. In the illustrated embodiment, the tip 247 is a standard luer connector that can be coupled to the connector 128 via one or more suitable adaptors. The tip 247 further defines a lumen or bore 249 having an inner diameter D_1 . In some embodiments, the diameter D_1 is about 0.103",

or about 0.080" to about 0.200", or about 0.100" to about 0.150", or about 0.100" to about 0.110". In some embodiments, the inner diameter D_1 is about 14 French.

During operation of the assembly 10, a user can first close the fluid control device 126 and then grip the plunger 242 and/or the barrel 244 to withdraw (e.g., retract) the plunger 242 at least partially out of the barrel 244 to thereby generate a vacuum in the barrel 244. Once the user has withdrawn the plunger 242 to a sufficient or desired volume, the user can lock the plunger 242 by rotating the plunger 242 relative to the barrel 244 such that the tab member 245 is positioned within a corresponding one of the slots 248. In other embodiments, the syringe 240 may not be a locking syringe, and the user can instead hold the plunger 242 in position relative to the barrel 244. Moreover, the user can control the volume of the vacuum—by withdrawing the plunger 242 more or less—to provide a desired amount or level of suction/aspiration upon opening of the fluid control device 126. In some embodiments, the syringe has a volume of about 60 cc or less than about 60 cc.

FIG. 3A is a side view of a pressure source 340 comprising a vacuum-pressure locking syringe ("syringe 340") configured in accordance with the present technology. The syringe 340 can have some features generally similar to the features of the syringe 240 described above with reference to FIG. 2. For example, the syringe 340 includes a plunger 342 slidably and rotatably positioned within a barrel 344, and the plunger 342 includes a plurality of index members 346 defining slots 348 between adjacent pairs thereof. The barrel 344 is shown as transparent in FIG. 3A (and FIG. 3C) for the sake of clarity. While withdrawing the plunger 342, a user can lock the plunger 342 at a specified volume by rotating the plunger 342 relative to the barrel 344 such that a tab member 345 on the interior surface of the barrel 344 is positioned within a corresponding one of the slots 348. In some embodiments, the syringe 340 has a maximum volume of about 60 cc or greater than 60 cc.

In the illustrated embodiment, the syringe 340 includes a large-bore tip 347, such as a Toomey tip, defining an inner lumen or bore 349. In some embodiments, the bore 349 can have an inner diameter D_2 that is greater than or equal to the largest inner diameter of the assembly 10 (e.g., of the catheter 102 and tubing subsystem 120). In certain embodiments, the tip 347 can be about 26 French or greater. Accordingly, referring to FIGS. 2 and 3A together, the diameter D_2 can be greater than the dimension D_1 . For example, the dimension D_2 can be about two, three, four, or more times greater than the diameter D_1 .

FIG. 3B is a side view of an adaptor 350 for connecting the syringe 340 to the catheter subsystem 100 configured in accordance with the present technology. FIG. 3C is a side view of the adaptor 350 coupled to the syringe 340, and FIG. 3D is a side view of the syringe 340 coupled to the tubing subsystem 120 via the adaptor 350. The adaptor 350 is shown as partially transparent in FIG. 3C for the sake of illustration. Referring to FIG. 3B, the adaptor 350 includes (i) a first portion 351 defining a first lumen or bore 352 having an inner diameter D_3 , (ii) a second portion 353 defining a second lumen or bore 354, and (iii) a stepped surface or interface 355 between the first and second portions 351, 353. The first portion 351 can further include a seal 357 such as an O-Ring around an exterior surface thereof.

Referring to FIGS. 3A-3D together, the second bore 354 of the adaptor 350 is configured to removably receive the tip 347 of the syringe 340 therein. In some embodiments, the tip 347 can be snugly received in the second bore 354 via an

interference fit. In some embodiments, a seal (e.g., an O-ring) can be positioned between an exterior surface of the tip 347 and an interior surface of the second bore 354. In other embodiments, the syringe 340 can be permanently coupled or integrally formed with the adaptor 350. The first portion 351 of the adaptor 350 is configured to be removably positioned within the connector 128 of the tubing subsystem 120 to fluidly couple the syringe 340 to the tubing subsystem 120. In some embodiments, the first portion 351 of the adaptor 350 can be pushed into the connector 128 until the interface 355 abuts the connector 128. When the first portion 351 of the adaptor 350 is positioned within the connector 128, the seal 357 seals the interface between the connector 128 and the adaptor 350.

The diameter D_3 of the first bore 352 of the adaptor 350 can be selected to be about the same as or greater than the greatest inner diameter of the assembly 10 (e.g., of the catheter 102 and the tubing subsystem 120). For example, the catheter 102 can be about 9 French or greater, and the diameter D_3 can be selected to be larger than the size of the catheter 102. Accordingly, when the fluid control device 126 is open, the continuous lumen between the catheter 102 and the syringe 340 can have a generally constant diameter and/or does not contain any narrowing at the interface between the syringe 340 and the tubing subsystem 120. That is, the adaptor 350 can connect the syringe 340 and the tubing subsystem 120 without any restriction or narrowing of the fluid path. In contrast, a standard luer connector (e.g., the syringe 240) can only provide a continuous lumen for catheters of about 8 French or smaller. Any narrowing of the fluid pathway between the catheter 102 and the syringe 340 can reduce the volumetric flow rate (e.g., suction forces and fluid velocities) that can be generated when a vacuum stored in the syringe 340 is applied to the catheter 102.

In general, the syringe 340 and the adaptor 350 can reduce the fluid resistance in the assembly 10 and therefore facilitate a more rapid pressure equalization in the assembly 10 when the fluid control device 126 is opened to apply the charged vacuum to the catheter 102. In some embodiments, for example, when the syringe 240 (FIG. 2) is charged with a 60 cc vacuum and the fluid control device 126 is opened, the pressure in the assembly 10 can take about 1-2 seconds to equalize. In contrast, when the syringe 340 is charged with a 60 cc vacuum and the fluid control device 126 is opened, the pressure in the assembly 10 can take less than about 1 second (e.g., about 0.5 seconds) to equalize. More specifically, Table 1 illustrates representative pressure equalization times and associated flow rates when the syringe 240 is coupled to a 20 French catheter (i.e., the catheter 102). Table 2 illustrates representative pressure equalization times and associated flow rates when the syringe 340 and the adaptor 350 are coupled to a 20 French catheter (i.e., the catheter 102).

TABLE 1

Pressure Equalization Time (seconds)	Flow Rate (cc/sec)
2.0	30.0
1.9	31.6
1.8	33.3
1.7	35.3
1.6	37.5
1.5	40.0
1.4	42.9
1.3	46.2

TABLE 2

Pressure Equalization Time (seconds)	Flow Rate (cc/sec)
0.9	66.7
0.8	75.0
0.7	85.7
0.6	100.0
0.5	120.0
0.4	150.0
0.3	200.0
0.2	300.0
0.1	600.0

In each instance, the syringe 340 provides for relatively faster equalization times and correspondingly greater flow rates. It is expected that the more rapid pressure equalization and flow rates provided by the syringe 340 will provide correspondingly greater suction forces at the distal portion 103a of the catheter 102. That is, in general, it is expected that increasing the bore size of a syringe used to provide vacuum pressure will provide greater suction forces over a smaller period of time (e.g., will provide a larger vacuum impulse). In some embodiments, the greater suction forces can facilitate the removal of clot material from a blood vessel of a patient even where the clot material is strongly lodged or attached within the blood vessel (e.g., a chronic clot).

Moreover, as shown in FIG. 3D, the adaptor 350 can couple the syringe 340 to the connector 128 without the need for any intervening tubing sections or additional adaptors. This arrangement can minimize the total length, volume, etc., of the components fluidly coupling the catheter 102 to the syringe 340. It is expected that the magnitude of suction forces generated at the distal portion 103a of the catheter 102—e.g., when a vacuum charged in the syringe 340 is applied to the catheter 102 by opening of the fluid control device 126—is proportional to the length of the fluid path between the pressure source 340 and catheter 102. Thus, operation of the assembly 10 with the syringe 340 and adaptor 350 is expected to increase the suction forces generated at the distal portion 103a of the catheter 102. In some embodiments, the greater suction forces can facilitate the removal of clot material from a blood vessel of a patient even where the clot material is strongly lodged or attached within the blood vessel (e.g., a chronic clot).

FIG. 4A is a side perspective view a pressure source 400 including the syringe 340 (“primary syringe 340”) shown in FIGS. 3A-3D and a secondary syringe 460 configured in accordance with the present technology. The secondary syringe 460 can include a plunger 462 slidably positioned within a chamber or barrel 464. The primary and secondary syringes 340, 460 can have the same volume or different volumes. In the illustrated embodiment, a tip 463 of the secondary syringe 460 is coupled to a first one-way valve (e.g., a check valve) 470 via a coupling member 465, such as a tube. The first one-way valve 470 is configured to fluidly connect the secondary syringe 460 to the ambient environment or another device coupled to the first one-way valve 470. A second one-way valve (e.g., a check valve) 472 spans between and is configured to fluidly connect the primary syringe 340 to the secondary syringe 460. More specially, in the illustrated embodiment the second one-way valve 472 is connected between the first portion 351 of the adaptor 350 and the coupling member 465. In other embodiments, the second one-way valve 472 can couple the primary and secondary syringes 340, 460 in different manners. For example, the second one-way valve 472 can span between

and directly connect the barrels 344,464. The primary and secondary syringes 340, 460 can be coupled or fastened together via one or more connectors 474 that fix the positions of the barrel 344, 464 relative to one another.

In some embodiments, the second one-way valve 472 is a normally-open check valve configured to (i) permit fluid (e.g., air) flow from the primary syringe 340 and the adaptor 350 to the secondary syringe 460 and (ii) inhibit fluid flow in the opposite direction from the secondary syringe 460 into the primary syringe 340. In some embodiments, the second one-way valve 472 has a cracking (e.g., opening) pressure of about 0 psi. In one aspect of the present technology, this arrangement maximizes the magnitude of the vacuum that can be charged within the primary syringe 340. That is, the cracking pressure of the second one-way valve 472 does not reduce the effective vacuum within the primary syringe 340. In other embodiments a normally-closed or other type of valve could be used for the second one-way valve 472. However, in such embodiments the vacuum efficiency of the pressure source 400 would be reduced by the cracking pressure of the second one-way valve 472. Similarly, the first one-way valve 470 can be a check valve configured to (i) permit fluid flow from the secondary syringe 460 to the ambient environment (or other device) and (ii) inhibit fluid flow in the opposite direction from the ambient environment into the secondary syringe 460.

FIGS. 4B and 4C are enlarged schematic side views of the pressure source 400 during operation. More specifically, FIGS. 4B and 4C illustrate fluid flow paths through the first and second one-way valves 470, 472 during retraction and advancement, respectively, of the plunger 462 through the barrel 464 of the secondary syringe 460. Referring first to FIGS. 4A and 4B together, during retraction/withdrawal of the plunger 462, (i) the first one-way valve 470 is closed to inhibit fluid from flowing into the secondary syringe 460 while (ii) the second one-way valve is open 472 to permit fluid to flow from the primary syringe 340, the catheter subsystem 100 (FIG. 1), and/or the tubing subsystem 120 (FIG. 1) into the secondary syringe 460. This flow path is indicated by the arrows R in FIG. 4B. Referring to FIGS. 4A and 4C together, during advancement of the plunger 462, (i) the first one-way valve 470 is open to permit fluid flow (e.g., fluid expulsion) from the secondary syringe 460 to the ambient environment (or other device) while (ii) the second one-way valve 472 is closed to inhibit fluid flow from the secondary syringe 460 into (e.g., back into) the primary syringe 360, the catheter subsystem 100, and/or the tubing subsystem 120. This flow path is indicated by the arrows A in FIG. 4C.

Referring to FIGS. 1 and 3A-4C together, the pressure source 400 can be coupled to the tubing subsystem 120 by coupling the primary syringe 340 to the connector 128 (e.g., as shown in FIG. 3D). When the pressure source is coupled to the tubing subsystem 120, retraction of the plunger 462 of the secondary syringe 460 evacuates an evacuable volume of the assembly 10. For example, when the fluid control device 126 is closed, retraction of the plunger 462 of the secondary syringe 460 evacuates fluid, through the second one-way valve 472, from (i) the primary syringe 340 (e.g., from the barrel 344, the tip 347, and/or the adaptor 350) and (ii) the portion of the tubing subsystem 120 between the fluid control device 126 and the primary syringe 340. This can enable a greater charged/stored vacuum to be generated for subsequent application to the catheter subsystem 100 for aspirating clot material. In some embodiments, the plunger 462 of the secondary syringe 460 can be withdrawn/advanced (e.g., “cycled”) one or more times before withdraw-

ing the plunger 342 of the primary syringe 340 to evacuate air from (i) the tip 347 of the primary syringe 340 and/or (ii) the portion of the tubing subsystem 120 between the fluid control device 126 and the tip 347. In other embodiments, the plunger 462 of the secondary syringe 460 can alternatively or additionally be withdrawn after withdrawing the plunger 342 of the primary syringe 340 to further evacuate the barrel 344 of the primary syringe 340. In some embodiments, the plunger 462 can be cycled when the fluid control device 126 is open to, for example, facilitate the removal of clot material stuck or clogged within the catheter subsystem 100. That is, cycling the secondary syringe 460 when the fluid control device 126 is open can generate vacuum pressure and suction in the catheter 102 to aid in the aspiration/removal of clot material.

In some embodiments, the volumes of the primary and secondary syringes 340, 460 can be selected based on one or more desired characteristics of a clot removal procedure using the pressure source 400. For example, the secondary syringe 460 can have a larger volume than the primary syringe 340 to permit a high vacuum to be charged within the primary syringe 340 while also limiting blood loss from the patient.

In one aspect of the present technology, the pressure source 340 permits a greater vacuum to be generated without increasing the volume of the primary syringe 340. For example, the vacuum generated by the primary syringe 340 alone is directly proportional to the volume of the primary syringe 340. Thus, to generate a greater vacuum using the primary syringe 340 alone, the volume of the primary syringe 340 must be increased. In contrast, inclusion of the secondary syringe 460 in the pressure source 400 and the configuration of the first and second one-way valves 470, 472 allows the (e.g., maximum) generated vacuum to be independent of the volume of the primary syringe 340. Therefore, for example, the generated vacuum can be increased without correspondingly increasing the volume of blood withdrawn from the patient when applying the vacuum to the catheter subsystem 100.

In some embodiments, (e.g., as described in greater detail below with reference to FIG. 19), the primary syringe 340 of the pressure source 400 can be replaced with a simple pressure vessel or other volume, such as a canister, barrel, tube, etc. In such embodiments, a vacuum can be generated in the canister simply by cycling the secondary syringe 460 one or more times. In some embodiments, the secondary syringe 460 can comprise a pump or vacuum source other than a syringe. Likewise, the secondary syringe 460 or other vacuum source can be fluidly coupled to the primary syringe 340 in other manners (e.g., via a different arrangement of check valves) to produce the same or similar flow patterns as shown in FIGS. 4B and 4C. Moreover, in some embodiments the first and second one-way valves 470, 472 can be other types of flow control devices that are mechanically activated/deactivated (e.g., opened and closed) rather than passively operated via pressure differentials within the pressure source 400. For example, the flow control devices 470, 472 can be mechanically coupled to the plunger 462 of the secondary syringe 460 such that cycling the plunger 462 activates/deactivates the flow control devices 470, 472 to operate the pressure source 400 in the manner illustrated in FIGS. 4B and 4C.

FIG. 5 is a side cross-sectional view of a pressure source 540 comprising an automatic release syringe (“syringe 540”) configured in accordance with the present technology. In general, the syringe 540 is configured to automatically apply a charged vacuum of a selected volume to the catheter

subsystem 100 without requiring the actuation of an intervening fluid control device, such as the fluid control device 126 shown in FIG. 1. The syringe 540 can have some features generally similar to the features of the syringes 240, 340 described in detail above with reference to FIGS. 2 and 3A-3D. For example, the syringe 540 includes a first plunger 542 slidably positioned within a chamber or barrel 544. The first plunger 542 further includes a first seal 543 that engages an interior surface of the barrel 544 such that a vacuum is formed within the barrel 544 as the first plunger 542 is withdrawn through the barrel 544. Likewise, referring to both FIGS. 1 and 5 together, the syringe 540 includes a tip 547 (e.g., a Toomey tip) for coupling the syringe 540 to the tubing subsystem 120 (e.g., via a Toomey tip adaptor) and defining a bore 549. In some embodiments, the bore 549 has a relatively large diameter selected to provide rapid pressure equalization in the assembly 10 after a vacuum stored in the syringe 540 is released.

The first plunger 542 can further include (i) a grip portion 541 configured to be engaged by a user for retracting the first plunger 542 and (ii) a lumen 581 extending lengthwise therethrough. In the illustrated embodiment, a plunger assembly 582 is slidably positioned within and extends through the lumen 581 of the first plunger 542. The plunger assembly 582 includes (i) a second plunger 583 and (ii) a release member 584 slidably and/or rotatably positioned within a lumen 585 of the second plunger 583. The release member 584 includes an engagement member 586 configured to engage the grip portion 541 of the first plunger 542 when the first plunger 542 is withdrawn from the barrel 544. The second plunger 583 includes a second seal 587 configured to engage and seal an interior surface of the bore 549 of the syringe 540 to enable a vacuum to be formed in the barrel 544 as the first plunger 542 is withdrawn through the barrel 544. That is, the second seal 587 can seal (e.g., fluidly disconnect) the barrel 544 of the syringe from the tubing subsystem 120 and the catheter subsystem 100. In some embodiments, the syringe 540 can further include an O-ring 579 or other suitable component for sealing an interface between the first and second plungers 542, 582 to maintain the vacuum formed within the barrel 544, while also permitting the first plunger 542 to move (e.g., translate) relative to the second plunger 583.

The plunger assembly 582 further includes a locking mechanism (not shown) configured to permit/inhibit the release member 584 from moving longitudinally relative to the second plunger 583. In some embodiments, for example, rotation of the release member 584 in a first direction relative to the second plunger 583 can lock the two components in position, while rotation of the release member 584 in a second direction relative to the second plunger 583 can unlock the two components so that the release member 584 can be withdrawn or pushed into the lumen 585 of the second plunger 583. In other embodiments, the release member 584 and the second plunger 583 can be integrally formed or permanently locked together.

The plunger assembly 582 enables (i) a user of the syringe 540 to select a desired volume for a vacuum to be formed in the syringe 540 and (ii) the automatic release or application of a generated vacuum via opening (e.g., unplugging) of the bore 549. Specifically, during operation of the syringe 540, a user can first unlock the release member 584 and slide the release member 584 to a position corresponding to a desired vacuum volume. For example, the release member 584 can have tick marks 588 or other indicia along its length that correspond to a volume of the syringe 540 (e.g., a vacuum chamber volume). After selecting a desired volume, the user

can lock the release member 584 relative to the second plunger 583 (e.g., by rotating the release member 584) to inhibit relative movement of the two components. After locking the release member 584, the user can grasp the grip portion 541 to retract the first plunger 542 relative to the barrel 544 and the plunger assembly 582 to generate a vacuum within the barrel 544 between the first and second seals 543, 587. When the first plunger 542 has been retracted to the desired volume, the grip portion 541 engages the engagement member 586 of the release member 584 such that further retraction of the first plunger 542 simultaneously retracts the plunger assembly 582. As the plunger assembly 582 is retracted, the second seal 587 of the second plunger 583 is pulled out of the bore 549, thereby releasing the vacuum stored in the barrel 544. In this manner, the syringe 540 provides for the automatic release of charged vacuum pressure at a specified volume and with a single retraction of the first plunger 542. Put differently, the syringe 540 has a built-in fluid control device and thus eliminates the need for a separate fluid control device 126 and/or an additional step for opening the fluid control device 126.

FIG. 6 is a top perspective view of a pressure source 640 comprising a syringe ("syringe 640") configured in accordance with the present technology. The syringe 640 can include some features generally similar to the features of the syringes 240, 340, and 540 described in detail above with reference to FIGS. 2-3D and 5. For example, the syringe 640 includes a plunger 642 slidably positioned within a barrel 644, and a tip 647 (e.g., a large-bore tip). In the illustrated embodiment, the syringe 640 further includes a lever or handle 690 operably coupled to the plunger 642. The handle 690 provides mechanical leverage for withdrawing the plunger 642 to create a vacuum within the barrel 644. More specifically, the handle 690 can be coupled to a crossbar 691 that rotates relative to the plunger 642 via actuation (e.g., rotation) of the handle 690. The crossbar 691 can be coupled to a gear (obscured in FIG. 6) configured to engage a track 692 on the plunger 642. Accordingly, rotation of the handle 690 in a first direction retracts the plunger 642 relative to the barrel 644 to charge a vacuum in the barrel 644. And, rotation of the handle 690 in a second (e.g., opposite) direction advances the plunger 642 into the barrel 644 to, for example, expel fluid, material, etc., from the barrel 644.

In one aspect of the present technology, the handle 690 provides additional mechanical leverage relative to a standard syringe, and can thus reduce the force (e.g., strain, energy, etc.) required by a user of the syringe 640 to form a vacuum in the syringe 640. Therefore, use of the syringe 640 can reduce the time needed to remove clot material with the assembly 10. In some embodiments, the syringe 640 can have a volume greater than 60 cc (e.g., greater than 80 cc, greater than 100 cc, greater than 120 cc, greater than 140 cc, etc.). In a particular embodiment, for example, the syringe 640 can have a volume of about 140 cc. With such large volumes, it may be difficult for some users to manually retract the plunger 642 without the additional mechanical leverage provided by the handle 690. Thus, the syringe 640 can enable the use of larger volume syringes that can generate correspondingly greater suction forces in the catheter subsystem 100.

Referring again to FIG. 1, it is expected that less tortuous (e.g., more linear) fluid paths between the pressure source 140 and the catheter subsystem 100 will produce greater suction forces and corresponding fluid velocities at the distal portion 103a of the catheter 102 when stored vacuum pressure is applied to the catheter subsystem 100. Accordingly, in some embodiments the side port 108 of the valve

106 can be formed to have an angle A that is less than about 90°, less than about 75°, less than about 60°, less than about 45°, less than about 30°, less than about 15° etc. Reducing the relative angle between the side port 108 and the lumen 109 of the valve 106 (and thus the lumen 104 of the catheter 102) reduces the tortuosity of the fluid path between the pressure source 140 and the catheter 102. Moreover, in some embodiments, the pressure source 140 can be coupled to the proximal portion 107b of the valve 106 instead of or in addition to the side port 108 to provide a more linear fluid path between the pressure source 140 and the catheter 102. For example, FIG. 24 is an enlarged isometric view of the assembly 10 showing the pressure source 340 coupled directly to the proximal portion 107b of the valve rather than to the connector 128 of the tubing subsystem 120 and the side port 108 of the valve 106. Although the pressure source 340 is illustrated in FIG. 24, any of the pressure sources described in detail above with reference to FIGS. 2-6 can be configured to be coupled to the proximal portion 107b of the valve 106 rather than the side port 108. In other embodiments, the side port 108 can be omitted and the valve 106 and the tubing subsystem 120 can be coupled to the catheter 102 via a Y-connector. For example, FIG. 25 is an enlarged isometric view of the assembly 10 showing the valve 106 and the tubing subsystem 120 coupled to the catheter 102 via a Y-connector 2590. In yet other embodiments, the tubing system 120 is linearly coupled to the catheter 102, and the valve 106 protrudes at an angle from the catheter 102.

In some embodiments, however, a guidewire or other component is positioned within the valve 106 during the duration of a clot removal procedure (e.g., for delivering interventional devices to a treatment site within a patient). Accordingly, in some embodiments, to facilitate coupling of the pressure source 140 to the proximal portion 107b of the valve 106—even when a guidewire is inserted there-through—the pressure source 140 can be a syringe configured for over-wire delivery. For example, FIG. 7 is a side view of a pressure source 740 comprising a vacuum-pressure locking syringe (“syringe 740”) configured in accordance with the present technology for delivery and operation over a guidewire 794. The syringe 740 can have some features generally similar to the features of the syringe 340 described in detail above with reference to FIG. 3. For example, the syringe 740 includes a plunger 742 slidably and rotatably positioned within a barrel 744. The barrel 744 is shown as transparent in FIG. 7 for the sake of clarity. In the illustrated embodiment, the plunger 742 includes a lumen 796 (shown in broken lines) extending longitudinally therethrough. The guidewire 794 can be inserted through the lumen 796 of the plunger 742 such that the syringe 740 can be advanced over the guidewire 794 for attachment to the proximal portion 107b of the valve 106. The syringe 740 can further include one or more sealing components (e.g., valves, O-rings, etc.; not shown) for maintaining a seal between the guidewire 794 and the plunger 742 to permit build-up and storage of a vacuum in the barrel 744.

In general, one skilled in the art will understand that the various embodiments of pressure sources disclosed herein may be combined to, for example, include multiple pressure sources or pressure sources having different components or combinations of components. For example, in some embodiments the secondary syringe 460 (FIGS. 4A-4C) can be coupled via one or more one-way valves to the syringes 240, 540, 640 or 740 (FIGS. 2 and 5-7, respectively) to generate additional vacuum. In some embodiments, multiple pressure sources can be coupled to the catheter 102 via the tubing subsystem 120 and/or via the valve 106. Moreover, the

individual pressure sources can be the same or different, and can be coupled to the catheter subsystem 100 via a single fluid control device, such as the fluid control device 126, or can be coupled to the catheter subsystem 100 via separate fluid control devices. Therefore, the profile of the vacuum applied to the catheter 102 can be selected or adjusted by using multiple different pressure sources. For example, a specific vacuum profile can depend at least on (i) the individual characteristics of the multiple pressure sources (e.g., volume, bore-size, etc.), (ii) the manner in which the pressure sources are coupled to the catheter subsystem 100 (e.g., via individual valves, via the same valve, etc.), and (iii) the timing of the application or release of the vacuum of each pressure source to the catheter subsystem 100 (e.g., staggered release, simultaneous release, etc.). As one example, in some embodiments, the syringe 240 (FIG. 2) and the syringe 340 (FIG. 3) can both be coupled to the tubing subsystem 120 via, for example, a Y-connector. After charging both syringes 240, 340 with vacuum pressure, opening the fluid control device 126 can simultaneously apply the combined vacuum to the catheter 102. The larger-bored syringe 340 can provide a short but powerful impulse of vacuum pressure, while the smaller-bored syringe 240 can provide a longer and more sustained vacuum pull. This combination can apply a large, fast-acting suction force to dislodge and capture clot material in the catheter 102, and simultaneously apply a more sustained suction force to capture more clot material.

III. Selected Embodiments of Methods of Clot Removal

FIG. 8 is a flow diagram of a process or method 800 for operating a clot removal system including the assembly 10 to remove clot material from within a blood vessel (e.g., a pulmonary blood vessel) of a human patient in accordance with the present technology. FIGS. 9A-9C are side views of a proximal portion of the assembly 10, and FIGS. 10A and 10B are schematic illustrations of a distal portion of the assembly 10, during a clot removal procedure in accordance with embodiments of the present technology. In particular, FIGS. 9A-9C are side views of the assembly 10 including the syringe 340 and adaptor 350 (FIGS. 3A-3D), and FIGS. 10A and 10B are side views of the catheter 102 with the distal portion 103a of the catheter 102 positioned proximate to an embolism or clot material PE within a blood vessel BV (e.g., a pulmonary blood vessel). Although some features of the method 800 are described in the context of the embodiments shown in FIGS. 1, 3A-3D, and 9A-10B for the sake of illustration, one skilled in the art will readily understand that the method 800 can be carried out using other suitable systems and/or devices described herein. In particular, although described in the context of the syringe 340, the method 800 can be carried out using any one or combination of the pressure sources described in detail above with reference to FIGS. 2-7.

At block 802, the method 800 includes positioning the distal portion 103a of the catheter 102 proximate to clot material within a blood vessel of a human patient (e.g., at a treatment site). For example, in the embodiment illustrated in FIG. 10A, a distal terminus of the distal portion 103a of the catheter 102 is positioned proximate to a proximal portion of the clot material PE. It is expected that reducing the distance between the distal terminus of the catheter 102 and the proximal portion of the clot material PE—without contacting the clot material PE with the catheter 102—will maximize the suction forces on the clot material PE when

the fluid control device 126 is opened. It is also expected that reducing the distance (e.g., clearance) between the inner diameter of the blood vessel BV and the outer diameter of the catheter will maximize the suction forces on the clot material PE. However, in other embodiments, the distal terminus of the catheter 102 can be positioned at least partially within the clot material PE, or the distal terminus of the catheter 102 can be positioned distal of the clot material PE.

Access to the pulmonary vessels can be achieved through the patient's vasculature, for example, via the femoral vein. In some embodiments, the catheter subsystem 100 can include an introducer (e.g., a Y-connector with a hemostasis valve; not shown) that can be partially inserted into the femoral vein. A guidewire (not shown) can be guided into the femoral vein through the introducer and navigated through the right atrium, the tricuspid valve, the right ventricle, the pulmonary valve, and into the main pulmonary artery. Depending on the location of the embolism, the guidewire can be guided to one or more of the branches of the right pulmonary artery and/or the left pulmonary artery. In some embodiments, the guidewire can be extended entirely or partially through the clot material PE. In other embodiments, the guidewire can be extended to a location just proximal of the clot material PE. After positioning the guidewire, the catheter 102 can be placed over the guidewire and advanced (e.g., as indicated by arrow A1) to a position proximate to the clot material PE as illustrated in FIG. 10A.

In some embodiments, to confirm the position of the distal portion 103a of the catheter 102, a contrast agent can be injected through the catheter 102 and viewed using fluoroscopic imaging techniques, as is known in the art. In some embodiments, the valve 106 can be opened to determine the position of the distal portion 103a of the catheter 102 relative to the clot material PE. For example, the activation buttons 101 can be depressed to open the lumen 109 of the valve 106. If there is substantially no back-bleeding through the valve 106, the operator can determine that the distal portion 103a of the catheter 102 is fully engaged with the clot material PE. Conversely, if there is some back-bleeding through the valve 106, the operator can determine that the distal portion 103a of the catheter is not fully engaged with the clot material PE. Accordingly, to locate the distal portion 103a of the catheter 102 just proximal of the clot material PE, the operator can (i) first determine that distal portion 103a of the catheter is fully engaged with the clot material PE by activating the valve 106 and detecting no back-bleeding and (ii) then reposition the catheter 102 (e.g., by withdrawing the catheter 102 proximally) and activate the valve 106 until back-bleeding is detected—thereby confirming that the distal portion 103a of the catheter 102 is positioned proximal of the clot material PE. In some embodiments, the valve 106 can be opened during retraction of the catheter 102 until back-bleeding is detected. In other embodiments, the valve 106 can be closed during retraction of the catheter 102, and the catheter 106 can be retracted a set (e.g., predetermined) distance before the valve 106 is opened again. In one aspect of the present technology, determining the position of the distal portion 103a of the catheter 102 via activation of the valve 106 can be used when it is difficult to determine the position of the catheter 102 via radiographic techniques. In contrast, many conventional hemostasis valves cannot be activated in this manner.

In some embodiments, the guidewire can then be withdrawn while, in other embodiments, the guidewire can remain and can be used to guide other catheters (e.g., delivery catheters, additional aspiration catheters, etc.),

interventional devices, etc., to the treatment site. It will be understood, however, that other access locations into the venous circulatory system of a patient are possible and consistent with the present technology. For example, the user can gain access through the jugular vein, the subclavian vein, the brachial vein, or any other vein that connects or eventually leads to the superior vena cava. Use of other vessels that are closer to the right atrium of the patient's heart can also be advantageous as it reduces the length of the instruments needed to reach the pulmonary embolism.

At block 804, the method 800 includes coupling a pressure source (e.g., the syringe 340) to the catheter 102 via the fluid control device 126. For example, in the embodiment illustrated in FIG. 9A, the tip 347 (shown in FIGS. 3A and 3C but obscured in FIG. 9A) of the syringe 340 can be coupled to the connector 128 via the adaptor 350. Once the syringe 340 is coupled to the catheter 102, (i) opening the fluid control device 126 fluidly connects the syringe 340 to the lumen 104 of the catheter 102, and (ii) closing the fluid control device 126 fluidly disconnects the syringe 340 from the lumen 104 of the catheter 102. The fluid control device 126 is in an open position in FIG. 9A.

At block 806, the method 800 includes activating the syringe 340 to generate a vacuum while the fluid control device 126 is closed. For example, as shown in FIG. 9B, the user can first actuate the fluid control device 126 to close the fluid control device 126, and then retract the plunger 342 to generate a vacuum in the barrel 344 of the syringe 340. The user can subsequently lock the plunger 342 relative to the barrel 344, as described in detail above, to store or maintain a vacuum of known volume in the syringe 340. In this manner, the syringe 340 can be pre-charged with a vacuum before the vacuum is applied to the catheter 102. In contrast, many conventional aspiration techniques include activating a negative pressure source (e.g., a pump, a syringe, etc.) while the pressure source is fluidly connected to a lumen to be aspirated. In some embodiments, when the pressure source 400 with the secondary syringe 460 (FIGS. 4A-4C) is used with the primary syringe 340, the secondary syringe 460 can be cycled one or more times before or after retracting the plunger 342 to increase the vacuum pressure.

At block 808, the method 800 includes opening the fluid control device 126 to apply the vacuum to the lumen 104 of the catheter 102. For example, with reference to FIG. 9C, the user can actuate (e.g., twist a handle of) the fluid control device 126 to open the fluid control device 126 and apply the vacuum stored in the syringe 340 to the catheter subsystem 100. As shown in FIG. 10B, application of the vacuum causes suction at the distal tip 103a of the catheter 102 (e.g., as indicated by arrow A2) that aspirates at least a portion of the clot material PE from the blood vessel BV and into the lumen 104 of the catheter 102. In some embodiments, opening the fluid control device 126 instantaneously or nearly instantaneously generates suction at the distal portion 103a of the catheter 102. In certain embodiments, application of the vacuum can generate suction for less than about 1 second (e.g., about 0.5 second), substantially less than about 1 second (e.g., about 0.3 second, about 0.1 second, etc.) less than about 2 seconds, or greater than about 2 seconds—until the pressure in the assembly 10 equalizes. In some embodiments, depending on the volume of the vacuum chamber formed in the syringe 340 and the dimensions of the catheter subsystem 100 and the tubing subsystem 120 (e.g., where the syringe 340 has a volume that is greater than or about equal to a volume of the catheter subsystem 100), at least some of the clot material PE can be aspirated entirely through the lumen 104 of the catheter 102 and into the barrel

344 of the syringe 340. In some such embodiments, the user can determine whether subsequent steps for treating the clot material PE are necessary or desirable by visualizing the amount of clot material collected in the syringe 340. FIG. 9C, for example, illustrates the syringe 340 and the tubing subsystem 120 after the fluid control device 126 has been opened to apply the vacuum stored in the syringe 340 to the catheter 102. In the illustrated embodiment, some of the clot material PE is visible in the syringe 340.

In some embodiments, the fluid control device 126 or another fluid control device can be intermittently operated to provide discrete bursts of suction. For example, the fluid control device 126 can be quickly opened and closed to provide a first burst of suction (e.g., vacuum release) without fully equalizing the pressure in the assembly 10. The fluid control device 126 can then be opened again to provide a second burst of suction, or opened and closed repeatedly to provide a desired suction pattern. In some embodiments, the assembly 10 can be specifically configured to facilitate the application of multiple bursts of suction. For example, (i) the fluid control device 126 can be spring-loaded, electronically controlled, etc., to rapidly open and close the valve, and/or (ii) the pressure source 140 can have a large vacuum chamber and/or small bore size to increase the time required for pressure in the assembly 10 to equalize (e.g., to increase a discharge time of the pressure source 140).

Sometimes, as shown in FIG. 10B, discharging the vacuum stored in the pressure source to aspirate the lumen 104 of the catheter 102 may not remove all of the clot material PE (or a desired amount of the clot material PE) from the blood vessel BV. That is, a single aspiration may not adequately remove the clot material PE from the blood vessel BV. In such instances, the user of the assembly 10 may wish to again apply vacuum pressure (conduct an “aspiration pass”) to remove all or a portion of the remaining clot material PE in the blood vessel BV. In such instances, the pressure source can be disconnected from the tubing subsystem 120 and drained (e.g., aspirated clot removed) before the method 800 returns to block 802. For example, the adaptor 350 and the syringe 340 can be decoupled from the connector 128, and the plunger 342 can be pushed into the barrel 344 to expel the clot material PE and associated fluid from the barrel 344 via the tip 347. With the distal portion of the catheter 102 positioned proximate to the remaining clot material PE (e.g., unmoved relative the last aspiration pass), the pressure source can then be re-coupled to the connector 128 (block 804), primed again (block 806), and the vacuum pressure discharged (block 808) to aspirate all or a portion of the remaining clot material PE.

Blocks 802-808 can be repeated until a desired amount of clot material is removed from the patient or until the catheter 102 becomes clogged. In some embodiments, to check for clogging of the catheter 102, the fluid control device 126 and/or the valve 106 can be opened to check for back bleeding. A lack of back bleeding can indicate that the catheter 102 is likely clogged. Similarly, if the barrel 344 of the syringe 340 contains mostly air and relatively little blood and clot material (e.g., less than 5-10 cc) after aspiration of the catheter 102 (block 808), it can indicate that the catheter 102 is likely clogged. When the catheter 102 is clogged or a sufficient amount of clot material PE has been removed from the patient, the method 800 can proceed to block 810 and the catheter 102 can be removed from the patient. When the catheter 102 is clogged, the catheter 102 can be flushed and cleared prior to reentry into the patient (block 802). In other embodiments, a different (e.g., new, unused, etc.)

catheter can be inserted into the patient and positioned to remove the remaining clot material PE from the patient.

In some embodiments, rather than removing the catheter 102 from the patient if the catheter 102 is clogged, the syringe 340 can be recharged and used to apply one or more subsequent vacuum pulses to the catheter 102. More specifically, the fluid control device 126 can be closed and the syringe 340 can be removed from the connector 128 and evacuated to remove the clot material and blood therein. Then, blocks 804-808 can be repeated to apply another pulse of vacuum to the catheter 102. That is, rather than removing the catheter 102 after a clog is detected, the syringe 340 can be “cycled” until the vacuum force on the clot material PE overcomes the forces between the clot material PE and the catheter 102 and sucks the clot material PE into the syringe 340. In some embodiments, when the pressure source 400 with the secondary syringe 460 (FIGS. 4A-4C) is used with the primary syringe 340, the secondary syringe 460 can be cycled one or more times to increase the vacuum in the assembly 10 (e.g., in the catheter 102) and thus increase the suction force exerted against the clot material PE. That is, rather than removing the catheter 102 after a clog is detected, the secondary syringe 460 can be cycled until the vacuum force on the clot material PE overcomes the forces between the clot material PE and the catheter 102 and sucks the clot material PE into the syringe 340. In some embodiments, as described in detail below with reference to FIGS. 15-16E, a second clot removal assembly can be telescoped through the first assembly 10 to facilitate removal of the clogged clot material PE.

In some embodiments, an interventional device such as a clot removal and/or clot treatment device can be delivered to the treatment site through the catheter 102 for engaging and facilitating clot removal before and/or after application of a stored vacuum to the catheter 102. Suitable interventional devices and associated methods are disclosed in U.S. Pat. No. 9,526,864, filed Jun. 9, 2015, and titled “RETRACTION AND ASPIRATION DEVICE FOR TREATING EMBOLISM AND ASSOCIATED SYSTEMS AND METHODS,” and U.S. Pat. No. 8,784,434, filed Mar. 15, 2013, and titled “METHODS AND APPARATUS FOR TREATING EMBOLISM,” both of which are incorporated herein by reference in their entireties. In some embodiments, for example, the user can first advance an interventional device to the treatment site and at least partially engage the clot material PE with the interventional device to loosen (e.g., scour) the clot material PE. Such loosening of the clot material PE can facilitate the removal of the clot material PE upon a subsequent aspiration pass. Likewise, in some embodiments, the user can use an interventional device to engage residual clot material PE (FIG. 10B) after a first aspiration pass.

IV. Selected Embodiments of Telescoping Clot Removal Systems and Associated Methods of Clot Removal

FIG. 11 is a partially schematic side view of another clot treatment or clot removal system configured in accordance with the present technology. In the illustrated embodiment, the clot removal system includes a first aspiration assembly 20 and a second aspiration assembly 30. The first and second aspiration assemblies 20, 30 (“assemblies 20, 30”) can include some features generally similar to the features of the aspiration assembly 10 described in detail above with reference to FIGS. 1-10B. For example, the first aspiration assembly 20 includes (i) a first catheter subsystem 1000

having a first catheter **1002** and a first valve **1006**, (ii) a first tubing subsystem **1020** having a first fluid control device **1026** (e.g., a stopcock), and (iii) a first pressure source **1040** that can be fluidly coupled to the first catheter subsystem **1000** via the first tubing subsystem **1020**. Likewise, the second aspiration assembly **30** includes (i) a second catheter subsystem **1100** having a second catheter **1102** and a second valve **1106**, (ii) a second tubing subsystem **1120** having a second fluid control device **1126** (e.g., a stopcock), and (iii) a second pressure source **1140** that can be fluidly coupled to the second catheter subsystem **1100** via the second tubing subsystem **1120**.

The first and second catheters **1002**, **1102** each comprise an elongated shaft defining a lumen **1004**, **1104** and having a distal portion **1003a**, **1103a**, respectively. The first and second valves **1006**, **1106** each include (i) a distal portion **1007a**, **1107a**, (ii) a proximal portion **1007b**, **1107b**, (iii) a lumen **1009**, **1109** extending therethrough, and (iv) a flow controller (obscured in FIG. **10**) in the lumen **1009**, **1109**, respectively. The first fluid control device **1026** is operable to regulate or control fluid flow between (e.g., fluidly connect or disconnect) the first pressure source **1040** and the first catheter subsystem **1000**. The second fluid control device **1126** is operable to regulate or control fluid flow between (e.g., fluidly connect or disconnect) the second pressure source **1140** and the second catheter subsystem **1100**.

In the illustrated embodiment, the second catheter **1102** has a smaller cross-sectional dimension (e.g., diameter) than the first catheter **1002** so that the second catheter **1102** can be inserted through the first valve **1006** and into the lumen **1004** of the first catheter **1002**. In some embodiments, the second catheter **1102** can be telescoped through the lumen **1004** of the first catheter **1002** until the distal portion **1103a** of the second catheter **1102** extends beyond a distal terminus of the first catheter **1002**. Accordingly, the second catheter **1102** can be longer than the first catheter **1002**. In some embodiments, the second catheter **1102** can have a size of 16 French or smaller and the first catheter **1002** can have a size of 20 French or greater. The first valve **1006** can provide a hemostatic seal that inhibits fluid flow (e.g., blood flow) through the first valve **1006** and from the first catheter subsystem **1000** when the second catheter **1102** is positioned within the first catheter **1002**. In some embodiments (e.g., as described in detail below with reference to FIGS. **14A-14C**), a sealing member **1499** can be positioned between the first catheter **1002** and the second catheter **1102** for sealing the lumen **1004** of the first catheter **1002** when the second catheter **1102** is advanced distally past the sealing member.

In some embodiments, the first and second pressure sources **1040**, **1140** (“pressure sources **1040**, **1140**”) are separate sources each configured to generate and store a vacuum for subsequent application to the first and second catheter subsystems **1000**, **1100**, respectively, as described in detail above with reference to FIGS. **1-10B**. In other embodiments, one or both of the pressure sources **1040**, **1140** can be configured to provide sustained negative pressure rather than a charge or burst of stored vacuum pressure. In yet other embodiments, one of the pressure sources **1040**, **1140** can be omitted, or the pressure sources **1040**, **1140** can be fluidly coupled and/or integrally formed.

FIG. **12** is a flow diagram of a process or method **1280** for operating a clot removal system including the assemblies **20** and **30** to remove clot material from within a blood vessel (e.g., a pulmonary blood vessel) of a human patient in accordance with the present technology. FIGS. **13A-13C** are schematic illustrations of a distal portion of the assemblies

20, **30** during a clot removal procedure in accordance with the present technology. FIGS. **14A-14C** are schematic side views of a distal portion of the assemblies **20**, **30** during a clot removal procedure and including an optional sealing member in accordance with the present technology. Although some features of the method **1280** are described in the context of the embodiments shown in FIGS. **11** and **13A-14C** for the sake of illustration, one skilled in the art will readily understand that the method **1280** can be carried out using other suitable systems and/or devices.

At block **1282**, the method **1280** includes intravascularly positioning the first catheter **1002** within a human patient. FIG. **13A**, for example, illustrates the first catheter **1002** after it has been advanced (e.g., as indicated by arrow **A1**) to a position within a blood vessel **BV** (e.g., a pulmonary blood vessel). More specifically, the first catheter **1002** can be advanced within the blood vessel **BV** until the distal portion **1003a** of the first catheter **1002** is positioned proximal to clot material **PE** within the blood vessel **BV**. In some embodiments, the position of the distal portion **1003a** of the first catheter **1002** relative to the clot material **PE** can be determined by activating the first valve **1006** and determining whether there is back-bleeding through the first valve **1006**, as described in detail above. In the illustrated embodiment, the clot material **PE** is located within a branch (e.g., a reduced diameter portion) of the blood vessel **BV**. In some embodiments, access to the blood vessel **BV** can be achieved using an introducer and guidewire as described in detail above with reference to FIG. **8**.

At block **1284**, the method **1280** includes advancing the second catheter **1102** through the first catheter **1002** until the distal portion **1103a** of the second catheter **1102** is positioned proximate to the clot material **PE** within the blood vessel **BV** (e.g., at a treatment site). To advance the second catheter **1102** through the first catheter **1002**, the user can first insert the distal portion **1103a** of the second catheter **1102** through the first valve **1006** before advancing the second catheter **1102** (e.g., as indicated by the arrow **A1**) through the lumen **1004** of the first catheter **1002**. In some embodiments, the first valve **1006** can be actuated (e.g., by depressing one or more buttons) to open the lumen **1009** of the first valve **1006** so that the second catheter **1102** can be inserted therethrough. In some embodiments, the position of the distal portion **1103a** of the second catheter **1102** relative to the clot material **PE** can be determined by activating the second valve **1106** and determining whether there is back-bleeding through the second valve **1106**, as described in detail above. In other embodiments, the (smaller) second catheter **1102** can be intravascularly positioned proximate to the clot material **PE** before intravascularly positioning the (larger) first catheter **1002**. In such embodiments, the second catheter **1102** can act as a guide or rail for guiding the advancement of the first catheter **1002** to the treatment site.

FIG. **13A** illustrates the second catheter **1102** after it has been advanced through the first catheter **1002** and past a distal terminus of the first catheter **1002** to position a distal terminus of the second catheter **1102** proximate to a proximal portion of the clot material **PE**. In other embodiments, the distal terminus of the second catheter **1102** can be positioned at least partially within the clot material **PE**, or the distal terminus of the second catheter **1102** can be positioned distal of the clot material **PE**. In one aspect of the present technology, because the second catheter **1102** has a smaller cross-sectional dimension than the first catheter **1002**, the second catheter **1102** can be advanced to narrower (e.g., more distal) treatment sites within the blood vessel **BV**. In the embodiment illustrated in FIG. **13A**, for example, the

first catheter **1002** may be too large to be positioned within the branch of the blood vessel **BV**, while the second catheter **1102** can be positioned within the branch proximate to or within the clot material **PE**.

At block **1286**, the method **1280** includes coupling the second pressure source **1140** to the second catheter **1102** via the second fluid control device **1126**. For example, any one or combination of the pressure sources described in detail above with reference to FIGS. **2-7** can be coupled to the second catheter **1102** via the second tubing subsystem **1120**. Once the second pressure source **1140** is coupled to the second catheter **1102**, (i) opening of the second fluid control device **1126** fluidly connects the second pressure source **1140** to the lumen **1104** of the second catheter **1102**, and (ii) closing of the second fluid control device **1126** fluidly disconnects the second pressure source **1140** from the lumen **1104** of the second catheter **1102**. In some embodiments, the method **1280** can further include coupling the first pressure source **1040** to the first catheter **1002** (e.g., via the first tubing subsystem **1020**).

At block **1288**, the method **1280** includes activating the second pressure source **1140** to generate a vacuum while the second fluid control device **1126** is closed. In particular, the second pressure source **1140** can be activated to build-up or pre-charge a vacuum for subsequent application to the second catheter **1102**. In some embodiments, the first pressure source **1040** can also be activated to generate and store a vacuum for subsequent application to the first catheter **1002**.

At block **1290**, the method **1280** includes opening the second fluid control device **1126** to apply the vacuum stored in second pressure source **1140** to the lumen **1104** of the second catheter **1102**. As shown in FIG. **13B**, application of the vacuum causes suction (e.g., as indicated by arrow **A2**) that aspirates at least a portion of the clot material **PE** from the blood vessel **BV** and into the lumen **1104** of the second catheter **1102**. In some embodiments, opening the second fluid control device **1126** instantaneously or nearly instantaneously generates suction at the distal portion **1103a** of the second catheter **1102**. In one aspect of the present technology, pre-charging or storing the vacuum before applying the vacuum to the lumen **1104** of the second catheter **1102** is expected to generate greater suction forces (and corresponding fluid flow velocities) at and/or near the distal portion **1103a** of the second catheter **1102** compared to simply activating the second pressure source **1140** while it is fluidly connected to the second catheter **1102**.

In some embodiments, where the first pressure source **1040** is also activated to generate and store a vacuum (e.g., at block **1288**), the method **1280** can further comprise opening the first fluid control device **1026** to generate suction at the distal portion **1003a** of the first catheter **1002**. One skilled in the art will understand that the suction profile in the blood vessel **BV** can be selected or modified based on the characteristics of the pressure sources **1040**, **1140** (e.g., volume, bore size, etc.) and the timing of the opening of the first and second fluid control devices **1026**, **1126**. For example, the first fluid control device **1026** can be opened at the same time as the second fluid control device **1126** to generate a combined and relatively large suction force in the blood vessel **BV**. In other embodiments, the first fluid control device **1026** can be opened after the second fluid control device **1126** to generate staggered or stepped suction forces in the blood vessel **BV**. For example, the first fluid control device **1026** can be opened after the second fluid control device **1126** to aspirate any of the clot material **PE** (i) remaining in the blood vessel **BV** after aspiration of the

second catheter **1102** and/or (ii) stuck to or extending from the second catheter **1102**. In other embodiments, the first pressure source **1040** can be a pump or other source for providing sustained negative pressure—rather than a built-up charge of negative pressure—and thus can generate sustained (e.g., constant) suction at the distal portion **1003a** of the first catheter **1002**. In some such embodiments, the first fluid control device **1026** can remain open during the clot removal procedure to provide sustained suction throughout the procedure.

In some embodiments, an interventional device can be delivered through the second catheter **1102** and used to engage the clot material **PE** before and/or after the vacuum is applied to the second catheter **1102**. Specific details of suitable interventional devices and associated methods of use are disclosed in, for example, provisional U.S. patent application Ser. No. 16/258,344, filed Jan. 25, 2019, and titled “SINGLE INSERTION DELIVERY SYSTEM FOR TREATING EMBOLISM AND ASSOCIATED SYSTEMS AND METHODS,” which is incorporated herein by reference in its entirety.

At block **1292**, the method **1280** includes retracting the second catheter **1102** proximally through the first catheter **1002**. In some embodiments, multiple aspiration passes can be performed with the second catheter **1102** before retracting the second catheter **1102**. In some embodiments, as shown in FIG. **13C**, the first pressure source **1040** or another pressure source coupled to the first catheter **1002** can be activated to generate suction (e.g., as indicated by arrow **A3**) at the distal portion **1003a** of the first catheter **1002** during retraction of the second catheter **1102**. The suction can be constant or provided in one or more bursts, as described in detail above. In some embodiments, the second catheter **1102** can be fully withdrawn from the patient and disposed of or cleaned (e.g., flushed with a sterile liquid) for reuse.

Sometimes, the clot material **PE** is not fully pulled into the second catheter **1102** when the vacuum is applied to the second catheter **1102** (block **1290**) and can therefore stick to or dangle from the distal portion **1103a** of the second catheter **1102**. FIG. **14A**, for example, is an enlarged view of the distal portion of the assemblies **20**, **30** shown in FIG. **13C** and illustrating a portion of the clot material **PE** stuck to or dangling from the distal portion **1103a** of the second catheter **1102**. In the illustrated embodiment, an optional seal **1499** is disposed between the first and second catheters **1002**, **1102** to facilitate the removal of such dangling clot material **PE**. More specifically, the seal **1499** (shown in cross-section) can be disposed between an outer surface of the second catheter **1102** and an inner surface of the first catheter **1002**. The seal **1499** can be an O-ring, grommet, or other suitable component that fluidly disconnects the lumen **1004** of the first catheter **1002** from the blood vessel **BV** when the second catheter **1102** is positioned therethrough (e.g., when the distal terminus of the second catheter **1102** is positioned distally of the seal **1499**).

FIGS. **14B** and **14C** are enlarged views of the distal portion of the assemblies **20**, **30** and illustrating further retraction of the second catheter **1102** (and the dangling clot material **PE**) into the lumen **1004** of the first catheter **1002**. In some embodiments, the first pressure source **1040** can be activated to charge a vacuum in the lumen **1004** of the first catheter **1002**. For example, after the second catheter **1102** is advanced through the first catheter **1002** and past the seal **1499** (e.g., block **1284**)—thereby sealing the lumen **1004** of the first catheter **1002**—the operator can open the first fluid control device **1026** and activate the first pressure source **1040** to build up the vacuum in the lumen **1004** of the first

catheter **1002**. Referring to FIG. **14C**, when the distal terminus of the second catheter **1102** is retracted proximally past the seal **1499**, the lumen **1004** of the first catheter **1002** becomes fluidly connected to the blood vessel BV and the vacuum is instantaneously or nearly instantaneously released to generate suction (e.g., as indicated by arrows **A4**). In the illustrated embodiment, the suction acts to separate or otherwise dislodge the clot material PE from the second catheter **1102** and pull the clot material PE proximally through the lumen **1004** of the first catheter **1002**. In this manner, a second burst of suction is automatically applied via the first catheter **1002** during retraction of the second catheter **1102**. In one aspect of the present technology, the user does not need to take any additional step to release the vacuum stored in the first catheter **1002**—as release is automatically triggered by retraction of the second catheter **1102**.

At block **1294**, the user can determine whether it is necessary or desirable to redeploy the second catheter **1102** or another catheter through the first catheter **1002** in order to remove any residual clot material PE that was not removed during the first aspiration pass and/or any clot material located elsewhere in the blood vessel BV (e.g., to initiate a second aspiration pass). In some embodiments, the operator can visualize the amount of clot material PE collected in the first pressure source **1040** and/or the second pressure source **1140** to at least partially determine whether another aspiration pass is needed. In other embodiments, the operator can rely on imaging (e.g., fluoroscopic imaging) of the blood vessel BV or other techniques known in the art to determine whether an additional aspiration pass is necessary or desirable.

If another pass is not needed (e.g., the clot material PE was adequately removed), the user can elect to fully withdraw the assemblies **20**, **30** from the patient at block **1296**. If clot material PE remains in the vessel, the method can return to block **1284**. In particular, the same second catheter **1102** can be cleaned (e.g., flushed with saline) and advanced again through the first catheter **1002** until the distal portion **1103a** of the second catheter **1102** is positioned proximate to the remaining clot material PE within the blood vessel BV. In some embodiments, a new second catheter **1102** can be used for each pass to reduce the likelihood of contamination (e.g., reintroduction of clot material PE). In some embodiments, the first catheter **1002** can be aspirated (e.g., via the first pressure source **1040**) prior to redeployment of the second catheter **1102** to, for example, remove any clot material PE that may be in the first catheter **1002** to inhibit its reintroduction into the blood vessel BV as the second catheter **1102** is advanced therethrough during another pass. Once the desired amount of clot material PE has been removed from the patient, the assemblies **20**, **30** may be fully withdrawn from the patient (block **1294**).

In one aspect of the present technology, the method **1280** provides for an aspiration catheter to be deployed multiple times without requiring that the first catheter **1002** be removed after each deployment. Accordingly, the present technology allows for only a single insertion of a guide catheter during a procedure including multiple passes to remove clot material—increasing the speed of the procedure and reducing trauma to the patient since the guide catheter does not need to be reintroduced (e.g., advanced through the vasculature and past the heart) before each pass. Moreover, in certain embodiments, the present technology can enable the first catheter **1002** to be relocated to an alternate treatment site within the patient without removing the first catheter **1002** from the patient and, therefore, without rein-

roducing the first catheter **1002** through the heart. For example, the first catheter **1002** can be relocated to another treatment site within the lungs including a treatment site in the opposite lung. More specifically, (i) a dilator can be reintroduced into the first catheter **1002**, (ii) the first catheter **1002** can be withdrawn into the main pulmonary artery, (iii) a guidewire can be redirected to the new treatment site, (iv) the first catheter **1002** can be advanced over the guidewire to the new treatment site, and (v) the dilator can be removed.

FIG. **15** is a flow diagram of another process or method **1580** for operating a clot removal system including the assemblies **20**, **30** (FIG. **1**) to remove clot material from within a blood vessel (e.g., a pulmonary blood vessel) of a human patient in accordance with the present technology.

FIG. **16A** is an enlarged side view of a distal portion of the first assembly **20**, and FIGS. **16B-16E** are side views of a distal portion of the assemblies **20**, **30** during a clot removal procedure in which clot material clogs the first assembly **20** in accordance with the present technology. Although some features of the method **1580** are described in the context of the embodiments shown in FIGS. **11** and **16A-16E** for the sake of illustration, one skilled in the art will readily understand that the method **1580** can be carried out using other suitable systems and/or devices.

Some features of the method **1580** are generally similar to those of the methods **880** and/or **1280** described in detail above with reference to FIGS. **8** and **12**, respectively. For example, at block **1582** the method includes intravascularly positioning the first catheter **1002** of the first assembly **20** within a human patient. At block **1584**, the method **1580** includes coupling the first pressure source **1040** to the first catheter **1002** via the first fluid control device **1026**. For example, any one or combination of the pressure sources described in detail above with reference to FIGS. **2-7** can be coupled to the second catheter **1002** via the first tubing subsystem **1020**. At block **1586**, the method **1580** includes activating the first pressure source **1040** to generate a vacuum while the first fluid control device **1026** is closed. In particular, the first pressure source **1040** can be activated to build-up or pre-charge a vacuum for subsequent application to the first catheter **1002**. At block **1588**, the method **1580** includes opening the first fluid control device **1026** to apply the vacuum stored in the first pressure source **1040** to the lumen **1004** of the first catheter **1002**. As described in detail above, opening the first fluid control device **1026** instantaneously or nearly instantaneously generates suction at the distal portion **1003a** of the first catheter **1002**.

Sometimes, however, clot material is not fully pulled into the first catheter **1002** and/or clogs the first catheter **1002** when the vacuum is applied to the first catheter **1002** (block **1588**). FIG. **16A**, for example, is an enlarged view of the distal portion of the first assembly **20** illustrating a portion of clot material PE that extends beyond from the distal portion **1003a** of the first catheter **1002** and blocks/clogs the lumen **1004** of the first catheter **1002**. As such, a portion of the clot material PE is not within the first catheter **1002**. Accordingly, at block **1590**, the method **1580** can include determining whether the first catheter **1002** is clogged. In some embodiments, the operator can determine that the first catheter **1002** is clogged based on the vacuum chamber of the first pressure source **1040** containing little to no clot material PE and blood. For example, since the clot material PE clogs the first catheter **1002**, the vacuum chamber of the first pressure source **1040** cavitates when the first fluid control device **1026** is opened. If the first catheter **1002** is not clogged, the method **1580** can proceed to block **1598** and the first catheter **1002** can be withdrawn from the patient or the

operator can perform another aspiration pass (e.g., as described in detail above with reference to blocks **808** and **810** of the method **800** shown in FIG. **8**).

If the first catheter **1002** is clogged, the method **1580** can proceed to block **1592** which includes advancing the second catheter **1102** through the first catheter **1002** until the distal portion **1103a** of the second catheter **1102** is positioned in or proximate to the clogging clot material PE. For example, FIG. **16B** illustrates the second catheter **1102** after it has been advanced to a position within the first catheter **1002** in which the distal terminus of the second catheter **1102** is at or proximate to the clogging clot material PE. To advance the second catheter **1102** through the first catheter **1002**, the user can first insert the distal portion **1103a** of the second catheter **1102** through the first valve **1006** (FIG. **11**) before advancing the second catheter **1102** through the lumen **1004** of the first catheter **1002**.

At block **1594**, the method **1580** includes activating the second pressure source **1140** (FIG. **11**) coupled to the second catheter **1102**. More specifically, the second pressure source **1140** (e.g., any one or combination of the pressure sources described in detail above with reference to FIGS. **2-7**) can be coupled to the second catheter **1102** via the second fluid control device **1126** (FIG. **11**), and the second pressure source **1140** can be activated to build-up or pre-charge a vacuum while the second fluid control device **1126** is closed. The second fluid control device **1126** can then be actuated to apply the vacuum stored in the second pressure source **1140** to the lumen **1104** of the second catheter **1102**. In other embodiments, the second pressure source **1140** can simply provide a sustained vacuum rather than an instantaneous release of vacuum. That is, in some embodiments the second pressure source **1140** is not pre-charged with a vacuum.

Applying the vacuum to second catheter **1102** can aspirate at least a portion of the clogging clot material PE into the second catheter **1102** and/or suck the clot material PE against the distal terminus of the second catheter **1102**. FIG. **16C**, for example, illustrates a portion of the clot material PE stuck to or extending from the distal portion **1103a** of the second catheter **1102** after aspirating the second catheter **1102**. In the embodiment illustrated in FIG. **16C**, the added vacuum pressure generated through the second catheter **1102** is still not enough to break apart the clot material PE such that it can be fully aspirated through the first and/or second catheters **1002**, **1102**. That is, the clot material PE clogs the lumen **1004** of the first catheter **1002**. In other embodiments, the added vacuum pressure from the second pressure source **1140** is sufficient to break apart the clot material PE such that it is aspirated into, for example, the vacuum chambers of the first and/or second pressure sources **1040**, **1140**.

At block **1596**, the method can include retracting the second catheter **1102** and the clot material PE through the lumen **1004** of the first catheter **1002**. For example, FIG. **16D** illustrates retracting the second catheter **1102**, which in turn retracts the attached clot material PE, through the lumen **1004** of the first catheter **1002**. In some embodiments, the second catheter **1102** and clot material PE can be fully withdrawn through the first catheter **1002**. In other embodiments, retracting the clot material PE through the first catheter **1002** causes the clot material PE to break apart and be aspirated into the vacuum chambers of the first and/or second pressure sources **1040**, **1140**. FIG. **16E**, for example, illustrates the clot material PE breaking apart as the vacuum of the first and/or second pressure sources **1040**, **1140** is instantaneously or nearly instantaneously released to suck the clot material PE proximally (e.g., as indicated by arrows **A5**).

At block **1598**, the first and second catheters **1002**, **1102** can be withdrawn from the patient or the operator can perform another aspiration pass using one or both of the first and second catheters **1002**, **1102**.

In one aspect of the present technology, the method **1580** removes clot material even when a first aspiration pass clogs the first catheter **1002**. More particularly, the second catheter **1102** can be used to remove clogged clot material PE without requiring the first catheter **1002** and the clogged clot material PE to be withdrawn through the blood vessel BV.

V. Additional Selected Embodiments of Clot Removal Systems and Associated Methods of Clot Removal

From the foregoing, it will be appreciated that specific embodiments of the present technology have been described herein for purposes of illustration, but that various modifications may be made without deviating from the scope of the present technology. For example, in many of the embodiments described above, stored vacuum pressure can be used to aspirate or suck clot material from a blood vessel and into a catheter without the need to engage an interventional device with the clot material. However, one skilled in the art will understand that the aspiration devices and techniques disclosed herein can be used in conjunction with any suitable interventional device and/or during a clot removal procedure utilizing an interventional device. In some embodiments, for example, a clot removal system can be configured to apply stored vacuum pressure to a guide catheter to generate a burst of suction while an interventional device is retracted into and/or through the guide catheter.

FIG. **17**, for example, is a partially schematic view of a clot removal system **1700** ("system **1700**") configured in accordance with the present technology. The system **1700** includes some features generally similar to the features of the clot removal system described in detail above with reference to FIG. **1**. For example, the system **1700** includes a catheter or sheath **1702** comprising an elongated shaft, and a valve **1706** coupled to a proximal portion of the sheath **1702**. The valve **1706** has a side port **1708** that fluidly couples a lumen of the sheath **1702** to a tubing subsystem **1720** and a pressure source **1740** (shown schematically). A fluid control device **1726** (e.g., a stopcock or clamp; shown schematically) is operable to fluidly disconnect or connect the pressure source **1740** from/to the lumen of the sheath **1702**. The pressure source **1740** can be any suitable pressure source for generating and storing vacuum pressure, as described in detail above.

In the illustrated embodiment, the system **1700** further includes (i) a self-expanding (e.g., mesh) funnel **1780** coupled to a proximal portion of the sheath **1702** and (ii) an interventional device (e.g., a thrombus extraction device) **1790**. In the illustrated embodiment, the interventional device **1790** includes an expandable coring element (e.g., a first portion) **1792** coupled to an expandable cylindrical element (e.g., a second portion) **1794**. In some embodiments, the interventional device **1790** is configured to self-expand from a compressed delivery state to an expanded deployed state. The interventional device **1790** is shown in the deployed state in FIG. **17**. An elongated shaft **1782** and/or one or more shafts positioned within the elongated shaft **1782** (e.g., an intermediate shaft **1884** and an inner shaft **1886** as shown in FIGS. **18E** and **18F**, respectively) are coupled to the interventional device **1790** and configured to retract, advance, and/or manipulate (e.g., move between the

delivery and deployed states) the interventional device **1790**. In some embodiments, the system **1700** can be generally the same as or similar to any of the clot removal systems disclosed in U.S. Patent Application Publication No. 2018/0193043, filed Apr. 26, 2017, and titled “DEVICES AND METHODS FOR TREATING VASCULAR OCCLUSION,” which is incorporated herein by reference in its entirety.

In the illustrated embodiment, the system **1700** is shown intravascularly positioned within a blood vessel BV of a human patient and proximate to clot material DV (e.g., a deep vein thrombus) within the blood vessel BV. Specifically, FIG. **17** shows the system **1700** after (i) advancing the sheath **1702** to a position proximate to a proximal portion **1785b** of the clot material DV, (ii) deploying the funnel **1780**, (iii) deploying the interventional device **1790** from the sheath **1702** (e.g., by advancing the interventional device **1790** through the valve **1706** and the sheath **1702** to a position distal of a distal portion **1785a** of the clot material DV), and (iv) expanding the interventional device **1790** from the compressed delivery state to the deployed state.

FIGS. **18A-18H** are enlarged views of a distal portion of the system **1700** during a clot removal procedure in accordance with the present technology. In general, FIGS. **18A-18H** illustrate the proximal retraction of the interventional device **1790** through the clot material DV to capture at least a portion of the clot material DV, and the subsequent joint retraction of the interventional device **1790** and the captured clot material DV into the funnel **1780** and the sheath **1702**. In one aspect of the present technology, charged vacuum pressure generated in the vacuum source **1740** can be applied to the sheath **1702** at one or more times during the illustrated process to generate suction for aspirating the captured clot material DV through the sheath **1702** and/or to inhibit clogging of the sheath **1702**.

Referring first to FIG. **18A**, proximal retraction of the interventional device **1790** causes the coring element **1792** to separate and/or core the distal end portion **1785a** of the clot material DV from the walls W of the blood vessel BV. As shown in FIG. **18B**, continued proximal retraction of the interventional device **1790** through the clot material DV causes the cylindrical element **1794** to capture the distal end portion **1785a** of the clot material therein. FIGS. **18C-18E** illustrate further proximal retraction of the interventional device **1790** which causes further separation, coring, and/or capture of the clot material DV. As seen in FIG. **18E**, the proximal end portion **1785b** of the clot material DV is cored and captured as the interventional device **1790** is proximally retracted toward the funnel **1780** and the sheath **1702**. As further shown in FIG. **18E**, a first radiopaque marker **1887a** can be positioned on a distal end portion of the inner shaft **1884** and a second radiopaque marker **1887b** can be positioned on a distal end portion of the sheath **1702**.

In some embodiments, as shown in FIG. **18F**, the interventional device **1790** can be proximally retracted until a portion of the coring element **1792** is contained (e.g., positioned) within the funnel **1780**. More specifically, the interventional device **1790** can be proximally retracted until a mouth **1895** of the coring element **1792** is contained within the funnel **1780**. In some embodiments, the containment of the mouth **1895** within the funnel **1780** can be fluoroscopically verified by visualization of the radiopaque markers **1887** (FIG. **18E**). In some embodiments, for example, the mouth **1895** can be determined as wholly contained within the funnel **1780** via fluoroscopic monitoring based on the alignment of the distal end portion of the inner shaft **1884** (e.g., the first radiopaque marker **1885a**) relative to the distal

end portion of the sheath **1702** (e.g., the second radiopaque marker **1885b**). In some embodiments, when the mouth **1895** of the coring element **1792** is positioned within the funnel **1780**, the interventional device **1790** can be moved or transformed from the expanded deployed state to the compressed delivery state to compress and secure the clot material DV captured by the interventional device **1790**. In some embodiments, for example, the intermediate shaft **1884** can be unlocked and/or decoupled from the inner shaft **1886** (e.g., via user actuation of a plunger or other device) such that the inner shaft **1886** can be advanced distally relative to the intermediate shaft **1884** to collapse or compress the interventional device **1790**.

After the interventional device **1790** has been collapsed, the interventional device **1790** can be proximally retracted through the funnel **1780** and into the sheath **1702** as depicted in FIG. **18G**. As shown in FIG. **18H**, the interventional device **1790** can continue to be proximally retracted until the interventional device **1790** and the captured clot material DV are fully contained within the sheath **1702**. In some embodiments, the interventional device **1790** and the captured clot material DV can then be withdrawn through the sheath **1702** and the valve **1706** (FIG. **17**), and from the patient's body.

In some embodiments, the collapse of the interventional device **1790** and/or the retraction of the interventional device **1790** into the funnel **1780** and/or the sheath **1702** can result in one or more portions of the clot material DV breaking away from the clot material DV contained in the interventional device **1790**. For example, all or a portion of the captured clot material DV can be extruded through pores of the (e.g., mesh) cylindrical element **1794** as the interventional device **1790** collapses. In some embodiments, any such clot material can be captured by the funnel **1780**. Referring to FIG. **17**, in some embodiments, the pressure source **1740** can be activated to charge a vacuum, and the fluid control device **1726** can subsequently be opened to apply the charged vacuum to the sheath **1702** (as described in detail above). The vacuum can be applied to the sheath **1702** at any point during retraction of the interventional device **1790**. As shown in FIGS. **18G** and **18H**, application of the vacuum can generate instantaneous or nearly instantaneous suction (e.g., as indicated by arrows **A6**) at the distal end portion the sheath **1702** that can aspirate the extruded portions and/or other portions of the clot material DV into and/or through the sheath **1702**. In particular, the generated suction can aspirate some or all of the clot material DV captured by the funnel **1780**. Moreover, in some embodiments, application of a vacuum from the pressure source **1740** can facilitate smooth retraction of the captured clot material DV through the sheath **1702**. For example, a burst of suction generated by application of the vacuum can help inhibit clogging of the sheath **1702**, and/or help resolve (e.g., break apart) a clog formed in the sheath **1702** during retraction.

VI. Selected Embodiments of Clot Removal Systems Having Filters and Associated Methods of Clot Removal

The systems and methods for clot removal described herein can include applying a pre-charged vacuum to generate suction for aspirating clot removal from the blood vessel of a patient. In one aspect of the present technology, aspiration of the clot material also aspirates blood from the patient. It can be advantageous to reintroduce the aspirated blood to the patient to lessen the trauma to the patient—

especially where the removal procedure may comprise multiple aspiration passes that can together withdraw a significant amount of blood. However, the aspirated blood is often mixed with clot material and is therefore not suitable for reintroduction into the patient. FIGS. 19-20E illustrate various devices for filtering aspirated blood from removed clot material to reintroduce the aspirated blood into the patient without reintroducing a significant amount of clot material.

For example, FIG. 19 is a perspective side view of a pressure source 1900 for filtering blood from aspirated clot material during a clot removal procedure configured in accordance with the present technology. The pressure source 1900 is generally similar to the pressure source 400 described in detail above with reference to FIGS. 4A-4C. For example, the pressure source 1900 includes the secondary syringe 460 ("syringe 460") and the first and second one-way valves 470 and 472. However, the secondary syringe 460 is coupled to a canister 1940 rather than the primary syringe 340 (FIGS. 4A-4C). The canister 1940 includes a tip (obscured) coupled to the adaptor 350 and is configured to be removably positioned within the connector 128 of the tubing subsystem 120 (FIG. 1) to fluidly couple the canister 1940 to the tubing subsystem 120. Because the canister 1940 does not include a plunger or other component for changing a volume thereof, the syringe 460 is the only vacuum source for evacuating the canister 1940 (e.g., via repeated cycling of the secondary syringe 460).

In the illustrated embodiment, the canister 1940 further includes a filter 1942. The canister 1940 is shown as transparent in FIG. 19 for the sake of clarity. The filter 1942 is coupled to and/or covers a removable end cap 1944 having a blood separation port 1946. In operation, when blood and clot material are aspirated into the canister 1940 (e.g., via any of the methods described in detail above), the filter 1942 separates the blood from the clot material within the canister 1940. The filtered blood can be removed via the blood separation port 1946. For example, a syringe (not shown) or other device can be fluidly coupled to the blood separation port 1946 and used to draw the blood through the filter 1942 and out of the canister 1940. The filtered blood can then be reintroduced to the patient via, for example, the fluid control device 126 and/or the connector 128 of the tubing subsystem 120. Once the blood is removed from the canister 1940, the end cap 1944 can be removed from the canister 1940 (e.g., by unscrewing the end cap 1944 from the body of the canister 1940) for removing the captured clot material. In some embodiments, the filter 1942 is attached to the end cap 1944 such that removing the end cap 1944 removes the filter 1942 and permits clot material to be dumped, scooped, or otherwise removed from the canister 1940.

FIGS. 20A-20E illustrate a filter device 2050 for filtering blood from aspirated clot material during a clot removal procedure configured in accordance with the present technology. The filter device 2050 is configured as an in-line filter for use with, for example, one or more of the pressure sources described in detail above with reference to FIGS. 2-7. For example, FIG. 20A is a partially-exploded side view of the filter device 2050 and the pressure source 340 (FIGS. 3A-3D). In the illustrated embodiment, the filter device 2050 comprises a filter portion 2060 that is removably positionable within a barrel portion 2070. In the illustrated embodiment, the barrel portion 2070 includes a barrel 2072 that defines a chamber 2074, and a large bore tip 2076 configured to fluidly couple the chamber 2074 to external components, such as the tubing subsystem 120 (e.g., as shown in FIG. 20C). The filter portion 2060 includes a seal 2062 configured to engage (i) an interior surface of the barrel 2072 when the

filter portion 2060 is positioned within the chamber 2074 of the barrel portion 2070 and (ii) an exterior surface of the syringe 340 (e.g., an exterior surface of the barrel 344) when the syringe 340 is inserted into the filter device 2050. In other embodiments, the filter portion 2060 can be permanently attached to or integrally formed with the barrel portion 2070. The filter portion 2060 further includes a filter (e.g., a mesh) 2064 configured (e.g., sized and shaped) to inhibit clot material from passing therethrough. In some embodiments, the filter 2064 can be configured to inhibit clots larger than about 100 μm (e.g., larger than about 110 μm) from passing therethrough.

FIG. 20B is a perspective side view of the syringe 340 coupled to the filter device 2050. The barrel 2072 of the barrel portion 2070 is shown as transparent in FIG. 20B (and FIGS. 20C-20E) for the sake of clarity. In the illustrated embodiment, the seal 2062 is positioned between the exterior surface of the barrel 344 of the syringe 340 and the interior surface of the barrel 2072 of the barrel portion 2070. The filter 2064 is positioned around (e.g., covers) the tip 347 of the syringe 340 to inhibit clot material from entering the barrel 344 of the syringe 340 during operation.

FIG. 20C is a side view of the filter device 2050 and syringe 340 coupled to the tubing subsystem 120 of the assembly 10. More specifically, the tip 2076 can be inserted into the connector 128 of the tubing subsystem 120 as described in detail above. When the filter device 2050 and the syringe 340 are coupled to the tubing subsystem 120, the filter device 2050 is positioned in-line (e.g., in series) with the syringe 340. In the embodiment illustrated in FIG. 20C, the plunger 342 of the syringe 340 has been withdrawn to generate negative pressure in the combined volume of the barrels 2072 and 344. As described in detail above, opening the fluid control device 126 nearly instantaneously applies the negative pressure to the catheter 102 to generate suction therein. When clot material and blood are aspirated through the catheter 102 and the tubing subsystem 120, the filter portion 2060 inhibits the clot material from entering the barrel 344 of the syringe 340. Thus, aspirated blood is collected in the barrel 344 of the syringe 340 while the aspirated clot material is collected in the barrel 2072 of the barrel portion 2070 of the filter device 2050. In this manner, clot material and blood can be separated during aspiration.

In one aspect of the present technology, separating the blood from the clot material such that the blood is within the syringe 340 permits the blood to be easily reintroduced to the patient. For example, FIGS. 20D and 20E are side views of the syringe 340 coupled to the tubing subsystem 120 of the assembly 10 for reintroducing blood to a patient. In some embodiments, as shown in FIG. 20D, the syringe 340 can be decoupled from the filter device 2050 and directly coupled to the connector 128. With the fluid control device 126 in an open position, the blood can then be reintroduced to the patient through the assembly 10 by depressing the plunger 342 of the syringe 340. In some embodiments, as shown in FIG. 20E, the syringe 340 can be decoupled from the filter device 2050 and directly coupled to a port on the fluid control device 126. With the fluid control device 126 in a closed position, the blood can then be reintroduced to the patient through the assembly 10 by depressing the plunger 342 of the syringe 340. Referring to FIGS. 20A-20E together, after or before reintroducing filtered blood to the patient, the filter portion 2060 of the filter device 2050 can be removed from the barrel portion 2070 so that the collected clot material can be removed and the filter device 2050 cleaned. In some embodiments, the filter device 2050 and a coupled pressure source can be used to filter blood

from clot material after—as opposed to during—an aspiration pass. For example, the filter device **2050** and coupled pressure source could be used to withdraw blood and clot material collected in the canister **1940** of the pressure source **1900** (e.g., where the canister **1940** does not include the filter **1942**).

FIGS. **21A** and **21B** illustrate a filter device **2150** for filtering blood from aspirated clot material during a clot removal procedure configured in accordance with the present technology. The filter device **2150** is configured for use with, for example, one or more of the pressure sources described in detail above with reference to FIGS. **2-7**. For example, FIG. **21A** is a partially-exploded side view of the filter device **2150** and the pressure source **340** (FIGS. **3A-3D**). In the illustrated embodiment, the filter device **2150** includes a housing **2152** defining a chamber **2154**, a filter **2156** configured to be positioned within the housing **2152**, and a cap assembly **2160** configured to be releasably coupled to the housing **2152** (e.g., via a threaded connection, snap-fit connection, etc.). In some embodiments, the filter **2156** can have a porosity of between about 50-200 microns.

The housing **2152** can include a port **2153** configured to be removably, fluidly coupled to the pressure source **340** via a tubing subsystem **2120**. In the illustrated embodiment, the tubing subsystem **2120** includes tubing sections **2124** (individually labeled as a first tubing section **2124a** and a second tubing section **2124b**), a fluid control device **2126** (e.g., a valve, stop cock, clamp, etc.), and a connector **2128** (e.g., a large bore connector) for fluidly coupling the tubing subsystem **2120** to the pressure source **340**. In the illustrated embodiment, the cap assembly **2160** includes a fluid connector **2162** (e.g., a standard Luer or large bore connector) configured to be connected to a receiving/reinfusion syringe **2170** via, for example, a tubing section **2164**. In some embodiments, the cap assembly **2160** can include a valve (e.g., a one-way valve, a check valve, etc.) that provides for one-way fluid flow through filter assembly **2150**.

In operation, during a clot removal procedure, the pressure source **340** can be decoupled from the connector **128** (FIG. **1**) after an aspiration pass and when the pressure source **340** is full of blood and clot material. After connecting the filter device **2150** to the receiving syringe **2170**, the pressure source **340** can be coupled to the filter device **2150**. For example, FIG. **21B** is a perspective side view of the filter device **2150** coupled to (i) the pressure source **340** via the tubing subsystem **2120** and (ii) the reinfusion syringe **2170** via the tubing section **2164**. More specifically, referring to FIGS. **21A** and **21B** together, the tip **347** of the pressure source **340** can be coupled to the connector **2128** of the tubing subsystem **2120**, and a tip **2172** of the reinfusion syringe **2170** can be coupled to the tubing section **2164**. In other embodiments, the filter device **2150** can be coupled to the pressure source **340** and/or the reinfusion syringe **2170** in other manners (e.g., directly such that the all or part of the tubing subsystem **120** is omitted). Alternatively, the filter device **2150** can be directly attached to the side port **108** (FIG. **1**), an IV line (not shown), or another suitable connection point for reintroducing blood to the patient.

After coupling the pressure source **340** to the filter device **2150**, the fluid control device **2128** can be opened to fluidly connect the pressure source **340** to the filter device **2150**. Then, the operator can depress the plunger **342** of the pressure source **340** to drive the blood and clot material from the pressure source **340** into and/or through the filter device **2150**. The filter **2156** of the filter device **2150** filters the blood from the clot material such that the blood flows into the reinfusion syringe **2170** and the clot material remains in

the chamber **2154** of the filter device **2150**. For example, as shown in FIG. **21B**, blood **B** fills the reinfusion syringe **2170** and clot material **PE** remains within the chamber **2154** of the filter device **2150** after depressing the plunger **342** of the pressure source **340** in the direction indicated by the arrow **H**.

Next, the reinfusion syringe **2170** can be decoupled from the filter device **2150** so that the blood **B** can be reintroduced to the patient. For example, the reinfusion syringe **2170** could be directly coupled to a port on the fluid control device **126** (FIG. **1**). The cap assembly **2160** can be decoupled from the housing **2152** of the filter device **2150** to, for example, permit an operator to remove the clot material **PE** collected in the housing **2152** and thereby clean and prepare the filter device **2150** for another use.

FIG. **22** is a partially-exploded side view of a filter device **2250** for filtering blood from aspirated clot material during a clot removal procedure configured in accordance with the present technology. The filter device **2250** is configured for use with, for example, one or more of the pressure sources described in detail above with reference to FIGS. **2-7**. In general, the filter device **2250** is generally similar to the filter device **2150** described in detail with reference to FIGS. **21A** and **21B**. For example, the filter device **2250** includes a housing **2252** defining a chamber **2254**, a filter **2256** configured to be positioned within the housing **2252**, and a cap assembly **2260** configured to be releasably coupled to the housing **2252**. However, in the illustrated embodiment the filter device **2250** includes a port **2253** that is directly connected to a connector **2228** configured to be coupled to a pressure source (e.g., the pressure source **340** shown in FIGS. **3A-3D**). The cap assembly **2260** includes a fluid connector **2162** (e.g., a standard Luer or large bore connector) configured to be connected to a reinfusion syringe, a sheath, an IV line, etc., (not shown). In some embodiments, the fluid connector **2262** is angled relative to the filter **2260** and/or the housing **2252**. For example, the fluid connector **2262** is formed to have an approximately right angle in FIG. **22**. In one aspect of the present technology, this arrangement makes the filter device more ergonomic during use.

FIG. **23** is a partially-exploded side view of a filter device **2350** for filtering blood from aspirated clot material during a clot removal procedure configured in accordance with the present technology. The filter device **2350** is configured for use with, for example, one or more of the pressure sources described in detail above with reference to FIGS. **2-7**. The filter device **2350** is generally identical to the filter device **2250** described in detail with reference to FIG. **22**—including, for example, the housing **2252** (“a first housing **2252**”), the filter **2256** (“a first filter **2256**”), and the cap assembly **2260** including the fluid connector **2262** (“a first fluid connector **2262**”). However, in the illustrated embodiment a second housing **2382** and a second filter **2386** are fluidly connected to the fluid connector **2262**. The second housing **2382** includes a second fluid connector **2384** that can be fluidly connected to a reinfusion syringe, a sheath, an IV line, etc., (not shown). The second filter **2386** is configured to provide a second stage of filtration. For example, in some embodiments the first filter **2256** has a larger porosity than the second filter **2386**. For example, the first filter **2256** can have a porosity of between about 50-200 microns and the second filter **2386** can have a porosity of between about 50-170 microns.

In general, one skilled in the art will understand that the various embodiments of filter devices disclosed herein may have different components or combinations of components. For example, the filter devices **2050**, **2150**, **2250**, and/or

2350 (“the filter devices”) could be utilized with any of several different pressure sources other than the syringe 340 (e.g., those shown in FIGS. 2 and 4-7). In some embodiments, the filter devices can be formed as a component of the tubing subsystem 120 (FIG. 1). Moreover, the filter devices can include any number of filters and/or housings to provide any number of filtration stages.

CONCLUSION

The above detailed descriptions of embodiments of the technology are not intended to be exhaustive or to limit the technology to the precise form disclosed above. Although specific embodiments of, and examples for, the technology are described above for illustrative purposes, various equivalent modifications are possible within the scope of the technology as those skilled in the relevant art will recognize. For example, although steps are presented in a given order, alternative embodiments may perform steps in a different order. The various embodiments described herein may also be combined to provide further embodiments.

From the foregoing, it will be appreciated that specific embodiments of the technology have been described herein for purposes of illustration, but well-known structures and functions have not been shown or described in detail to avoid unnecessarily obscuring the description of the embodiments of the technology. Where the context permits, singular or plural terms may also include the plural or singular term, respectively.

Moreover, unless the word “or” is expressly limited to mean only a single item exclusive from the other items in reference to a list of two or more items, then the use of “or” in such a list is to be interpreted as including (a) any single item in the list, (b) all of the items in the list, or (c) any combination of the items in the list. Additionally, the term “comprising” is used throughout to mean including at least the recited feature(s) such that any greater number of the same feature and/or additional types of other features are not precluded. It will also be appreciated that specific embodiments have been described herein for purposes of illustration, but that various modifications may be made without deviating from the technology. Further, while advantages associated with some embodiments of the technology have been described in the context of those embodiments, other embodiments may also exhibit such advantages, and not all embodiments need necessarily exhibit such advantages to fall within the scope of the technology. Accordingly, the disclosure and associated technology can encompass other embodiments not expressly shown or described herein.

We claim:

1. A method for the treatment of clot material within a vasculature of a patient, the method comprising:
 positioning an aspiration catheter at least partially within the vasculature proximate to the clot material;
 fluidly coupling a first chamber to an aspiration pump;
 fluidly coupling the first chamber to a second chamber distal of the first chamber;
 positioning a filter within the second chamber;
 selectively fluidly coupling the aspiration catheter to the second chamber via a user-actuatable valve positioned between the second chamber and the aspiration catheter;
 with the valve closed to inhibit fluid flow from the aspiration catheter to the second chamber, generating negative pressure in the first and second chambers;

after generating the negative pressure, opening the valve via a user actuation such that fluid flow at least partially from the second chamber into the first chamber causes rapid aspiration of blood and at least a portion of the clot material into the second chamber, wherein the filter is configured to filter the blood from the portion of the clot material; and
 reintroducing the filtered blood into the vasculature of the patient.

2. The method of claim 1 wherein reintroducing the filtered blood into the patient includes directing the filtered blood distally through the aspiration catheter.

3. The method of claim 1 wherein the clot material comprises a pulmonary embolism.

4. The method of claim 1 wherein the clot material comprises a deep vein thrombus.

5. The method of claim 1 wherein the method further comprises selectively providing fluid access to a lumen of the aspiration catheter via a hemostasis valve fluidly coupled to the lumen of the aspiration catheter.

6. The method of claim 5 wherein the second chamber, the aspiration catheter, and the hemostasis valve form a coupled assembly.

7. The method of claim 6 wherein the second chamber is removably carried by the coupled assembly.

8. The method of claim 5 wherein the method further comprises advancing a second catheter at least partially through the hemostasis valve and the lumen of the aspiration catheter.

9. The method of claim 8 wherein advancing the second catheter at least partially through the hemostasis valve includes sliding the second catheter through a lumen of a tubular member of the hemostasis valve, wherein the hemostasis valve further comprises a filament extending at least partially around the tubular member, and wherein the filament is moveable between (a) a first position wherein the filament circumferentially constricts the lumen to create a seal around the second catheter and (b) a second position wherein the filament is moved to at least partially open the lumen.

10. The method of claim 1 wherein the second chamber is removably coupled between the aspiration pump and the aspiration catheter.

11. The method of claim 1 wherein the first chamber has a first volume, and wherein the second chamber has a second volume smaller than the first volume.

12. The method of claim 1 wherein reintroducing the filtered blood into the patient includes directing the filtered blood distally through a catheter separate from the aspiration catheter.

13. The method of claim 1 wherein the method further comprises

removing the filter from within the second chamber; and
 clearing the portion of the clot material from within the second chamber.

14. The method of claim 1 wherein positioning the aspiration catheter at least partially within the vasculature proximate to the clot material includes positioning a distal end portion of the aspiration catheter proximal to the clot material.

15. The method of claim 1 wherein the clot material comprises a pulmonary embolism or deep vein thrombosis.